

THE RESIDUAL EFFECTS OF ZINC
FERTILIZERS ON THE GROWTH AND
NUTRIENT UPTAKE OF THE WHITE PEA BEAN
(PHASEOLUS VULGARIS VAR. SANILAC)
AND THE RED KIDNEY BEAN
(PHASEOLUS VULGARIS VAR.
CHARLEVOIX)

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ABSTRACT

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By

Somjate Jantawat

Field and laboratory studies were conducted to determine the residual effect of zinc fertilizers on the growth and nutrient uptake by white pea and red kidney beans.

The effect of zinc containing fertilizer upon the growth of bean plants could be measured fourteen days after planting. The growth rate, the number of leaves per plant, the number of pods per plant, the number of seeds per pod, and the seed yield were markedly increased by the use of zinc fertilizers. Maturity was also hastened. The growth rate of bean plants which received zinc fertilizers increased more rapidly than those not receiving zinc. The growth rate of the red kidney bean was more rapid than the white pea bean during the early part of the season, but the final dry plant weight and seed yield was greater than the red kidney bean.

The nitrogen uptake models of both varieties were similar and the rate of the uptake increased rapidly after twenty-eight days from planting.

The nitrogen content of the several plant parts varied greatly, but in the mature plants was concentrated in the seed and in the blade of the leaves.

The phosphorus uptake by both varieties of beans was similar. The uptake rate increased rapidly after twenty-eight days. At maturity the phosphorus was concentrated primarily in the seed. During the growing season the leaf blade contained a higher percent phosphorus than did the leaf petiole.

The percent potassium in the petiole was higher than in the leaf blade. The potassium uptake by both varieties of beans increased rapidly after fourteen days and reached the maximum rate at maturity.

The uptake rate of calcium increased during the growing season and a large amount of calcium was found in the leaf blade.

The magnesium levels in the bean varieties were about one-third those of the calcium. The magnesium accumulation was relatively high in the leaf blade.

The uptake rate of copper, iron, manganese and zinc followed a similar pattern, and increased rapidly after twenty-eight days after growth.

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TO

MY MOTHER AND ANCHAREE

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I. INTRODUCTION

The field bean is one of the more important cash crops in Michigan. The gross annual return to Michigan's 12,000 bean producers is 45 to 50 million dollars (41).

Large acreages of beans are produced in the Saginaw Valley and Thumb areas (23).

The soils associated with a deficiency of zinc are usually neutral to alkaline in reaction, and the more alkaline soils have a greater need for zinc. A visual deficiency is most likely to occur on soils with a pH above 7.2, and a deficiency frequently develops where calcareous subsoils are exposed by land leveling or erosion. Zinc deficiency is common on field beans grown directly over tile lines, where the subsoil has been mixed with the surface soil.

Recent experiments demonstrated that the use of zinc fertilizers increased the uptake of zinc and the yield of field beans.

A study of the effect of several inorganic carriers applied to beans and corn indicated that zinc sulfate was the most effective in increasing early plant growth and zinc uptake (11). The growth and nutrient uptake response was not always reflected in an increase in final yield. The same experiment showed that where low rate of zinc

were used, there was a relatively small residual effect from previous applications of zinc.

The following study was conducted to investigate the residual effect of zinc fertilization on the growth and nutrient uptake by white pea bean (*P. vulgaris* L. Var. Sanilac) and red kidney beans (*P. vulgaris* L. Var. Charlevoix). The study was divided into two parts labeled "field" and "laboratory."

Field work was conducted to evaluate the effect of certain zinc treatments upon the growth characteristics of red kidney and white pea beans.

The laboratory work was done on plant tissue collected from one plot. The purpose was to measure the growth rate of several parts of the plants and to determine the mineral content and uptake during the growing season.

II. REVIEW OF LITERATURE

Role of Zinc in Plants

According to Thompson (63), zinc has been recognized as an essential element since 1914. Schutte (56) reported that the primary role of zinc in the plant is that of a catalyst. Zinc is involved in the processes of chlorophyll synthesis and transpiration.

Nason et al. (44) and Tsui (65) believed that zinc was related to auxin synthesis because deficient plants were low in β -indole acetic acid (IAA), precursors to tryptophan and tryptophan synthetase. Chester and Robinson (17) postulated that zinc may be involved in the activity of the auxin β -indole acetic acid.

Quinlan-Watson (50) suggested that zinc is associated with aldolase activity in subterranean clover. Day and Franklin (18) stated that zinc is located in the prosthetic group of carbonic anhydrase. Sayre (55) reported that zinc was located mostly in and around the primary vein of the corn leaf blade.

Seatz and Jurinak (59) state that several morphological and physiological changes were found in plants when the level of metabolically active zinc was inadequate. Among these changes were: 1) the palisade cells of leaves were abnormally large and were transversely rather than

columnarly divided; 2) the number of chloroplasts was reduced; 3) starch grains were absent; 4) oil droplets formed in the chloroplasts; and 5) phenolic materials and calcium oxalate crystals accumulated in the leaves. Hagi and Vallee (25) suggested that zinc might act as a bridge between protein and the pyridine nucleotide in yeast alcohol dehydrogenase.

The zinc content varies with age, species of plant and part of plant. Lyman and Dean (37) reported that the merismatic tissue of pineapple contained the largest concentration of zinc. Viets et al. (67) stated that the upper leaves of corn contain more zinc than the lower leaves in both normal and deficient plants.

Shaw et al. (60) found that zinc was not translocated in or from older tissue.

Reed (51) reported that the zinc content of the vegetative parts of peas and beans was much lower than the zinc content of immature seed.

Seatz et al. (58) reported that an equivalency of zinc and other bases was found throughout snap bean plants near early bloom stage. Millikan (42) stated that the top:root ratio was greater in plants adequately supplied with zinc.

Bonner and Varner (9) reported that the concentration of approximately 20 ppm. zinc in tops appears to be optimum for normal plant growth and metabolism. Haitt and Massey (26) and Viets et al. (69) found that zinc deficiency symptoms usually develop when the zinc content is below 15 to 20 ppm.

Seatz and Jurinak (59) stated that visual zinc deficiency symptoms in plant tops are interveinal chlorosis of lower leaves, and a shortening of internodes. A deficiency of zinc in the roots was indicated by an abnormal shape and large amount of fats and tannin but no starch. Barnette (1) reported that white bud of corn is typical of zinc deficiency symptoms. Stiles (61) stated that rosetting of fruit trees, mottled citrus leaves, and little leaf of beans are typical of several types of zinc deficiency symptoms.

Viets et al. (70) classified the following crops based upon sensitivity to zinc deficiency: very sensitive (beans, soybean, corn, hops, grapes, lima beans, flax, and castor beans); mildly sensitive (potatoes, onions, alfalfa, grain sorghum, sudan grass, sugar beets and red clover), and insensitive (peppermint, oats, wheat, barley, rye, peas, asparagus, mustard, carrots, safflower and grasses). Brown and Tiffin (13) also reported that red kidney beans, okra, and tomatoes developed more acute deficiency symptoms than corn. Barley, wheat, haweye, soybeans, and millet developed no zinc deficiency when grown on the same soil.

Seatz and Jurinak (59) reported that zinc is essential for seed production in many plants, and is a component of glycylglycine dipeptidase and dihydropeptidase enzymes involved in protein metabolism. Boawn et al. (7) found that the number of days from bean planting to harvest maturity was related to the zinc concentration of either leaf tissue or total top tissue at or prior to the bloom stage. Chapman (15) suggested that leaf analysis is probably the best

diagnosis technique for determining a zinc deficiency and also for evaluating a zinc toxicity.

Russell (54) stated that weeds and grasses, notably ragweed and lamb's quarter are able to obtain more zinc from soils that are low in zinc than most cultivated crops.

Zinc in Soil

Hibbard (27) found that surface soils contain more total zinc and more available zinc than subsoils. Mitchell (43) also showed that the zinc concentration in the A₁ horizon is higher than in any of the lower subsoil horizons and that the total content of zinc varies greatly between soil groups.

Swaine (62) reported that the usual amount of zinc in soil ranges between 10 and 300 ppm. Elanck (6) reported a lower and a narrower range of 2 to 50 ppm. Meturtney and Robinson (39) stated that the smallest quantities of available zinc were found in sandy soils low in organic matter.

John et al. (29) listed three fractions of soil zinc: 1) water soluble; 2) exchangeable; 3) relatively insoluble fraction composed of phosphates, carbonates, and silicates or other stable compounds. Bould and Hewitt (10) stated that zinc occurs in ferromagnesium minerals, magnetite, biotite, and hornblende.

Berger (3) reported that in the United States, zinc deficiencies are found in 31 states. Judy et al. (31) and Ellis (20) reported that in Michigan, zinc deficiencies occur most frequently in the Saginaw Valley and Thumb areas.

Lucas (36) stated that alkaline peats are likely to be deficient in zinc. Vinande et al. (71) and Ellis et al. (22) made similar observations on areas in Michigan where zinc deficiency is likely to occur.

Factors Affecting Zinc Availability

Phosphorus

Judy et al. (31) reported that heavy phosphorus fertilization intensified zinc deficiency. They found that extra phosphorus caused a decline in yield of pea beans and often a decreased zinc uptake. Winters and Parks (73) found that zinc deficiency of corn in Tennessee was most frequent in soil naturally high in phosphate. Roger and Wu (52) also found that zinc uptake by oats was decreased by the application of phosphate. Labanauskus et al. (33) reported that phosphate decreased the zinc content of avocado. Bingham and Martin (5) also reported that phosphate reduced zinc uptake by citrus. Judy et al. (30) reported that high residual soil phosphate levels reduced the yield of beans unless zinc was included with starter fertilizer.

Nitrogen

Viets et al. (68) reported that nitrogen fertilizer greatly increased the uptake of both native and applied zinc. Ellis et al. (21) found that many crops absorbed more soil zinc after nitrogen application. Ozane (46) however, found that an increased nitrogen supply depressed the zinc uptake in clover.

Other Nutrients

Greenwood and Hayfron (24) found that high K : Ca ratio in a calcareous soil resulted in the production of zinc deficiency symptoms while a low K : Ca ratio resulted in iron deficiency symptoms. Seatz (57) reported that the use of magnesium increased the zinc uptake by bean plants. Jurinak and Thorne (32) found that sodium and potassium increased zinc solubility in soils. Lee et al. (34) found that zinc appeared to interfere with iron uptake, whereas iron did not interfere with zinc uptake.

Soil Reaction

Winters and Parks (73) and Roger and Wu (52) reported that liming increased zinc deficiency. Camp (14) stated that the availability of zinc declined as the soil pH increased with the critical value being between pH 5.5 and 6.5. Judy et al. (30) found that zinc deficiencies were severe over tile lines, and where large quantities of fertilizer had been used on alkaline soils.

Massey (38) found that the zinc uptake by corn plants was significantly correlated with pH for a group of soils ranging from pH 4.3 to 7.5. Lee and Craddock (35) found that raising soil pH from 5.4 to approximately 6.4 with dolomitic limestone increased plant growth and soybean yields. Thus deficiencies were not induced within this range. Nelson et al. (45) studied the effect of pH on zinc availability. They found that the titratable alkalinity had to be considered as a factor in separating responding

from nonresponding soils.

Other Factors

Nelson et al. (45) suggested that the calcium carbonate content as well as soil pH may help to determine the availability of zinc.

Ellis et al. (22) reported that total zinc uptake by corn was decreased when the soil temperature was decreased from 75°F. to 55°F. Wallace et al. (72) studied the effect of soil temperature and zinc applications on the yield and micronutrient content of four crop species grown together in a greenhouse. They found that the yield of crop increased with soil temperature with or without zinc application. Cotton responded to zinc at the low soil temperature, bush beans at the high soil temperatures, and corn responded at all three temperatures used (14°, 20°, and 26°C). Thorne (62) reported that growing alfalfa increased the zinc availability for companion crops or for crops which follow alfalfa in the rotation. Roger et al. (53) found that land "resting" increased zinc availability.

Residual Effect of Zinc Fertilizer

Brown et al. (12) studied in the greenhouse, the residual effect of zinc applied to soil. They found that four milligram of zinc per pot of soil were sufficient for six or seven successive crops. Where 20 milligrams were used, there was sufficient zinc for more than ten successive crops. Brinkerhoff et al. (11) found that a combination of 24 pounds of zinc applied in 1962 with three pounds applied

at planting time in 1965 produced the most rapid early growth and uptake. Early growth and uptake were better than where less total zinc had been used. Vinande et al. (71) found that the residual effect of zinc fertilization increased plant weight, zinc uptake, and yield the following year.

Soil Testing for Zinc

Berger et al. (4) reported that the extraction of zinc with 0.1 N HCl is a useful method for acid soils. Nelson et al. (45) found that the line formed by plotting 0.1 N HCl extractable zinc against titratable alkalinity separated deficient soils from nondeficient soils. Tucker and Kurtz (66) found that 0.1 N HCl extracted amounts of zinc that were significantly correlated with a bioassay method. Barrow and Drosdoff (2) also found a significant correlation between response of tung trees and the amount of zinc extracted by 0.1 N HCl. Melton (40) reported that a 0.1 N HCl extraction procedure was found to be a good soil test for plant available zinc in Michigan.

III. EXPERIMENTAL METHODS

Field Plots

Field plots were established in 1965 in Saginaw County, Buena Vista Township, on the Wilbert Johnson farm, on a tile drained Sims clay loam soil. The original experiment was a randomized block design. The purpose was to test the residual effect of two carriers of zinc upon the yield and quality of the Sanilac bean. Sanilac beans were grown in 1965, 1966, and 1967.

In 1968 the plots were subdivided into several experiments involving some crops other than beans. One replication of the original experiment was used for this project in which two varieties of beans, a white pea bean and a red kidney bean, were planted across all of the treatments.

The outline and treatments of the original experiments are shown in Appendix I. The outline for the 1968 plan of work is shown in Appendix II.

The beans in 1968 were planted in 28 inch rows in moist soil on June 20 at the rate of 50 pounds of seed per acre. Weeds were well controlled by cultivation and hoeing.

The six plots were the source of plant material for the growth studies and yield determinations. One of the six plots was also used as a source of plant tissue for

chemical analysis.

Growth and Yield Studies

Numerous visual observations on the growth of the plants were made from 1965 through 1967. The same trends and general characteristics again were observed in 1968.

Plant samples were collected at two week intervals from each treatment area. The actual sampling dates were July 3, July 17, July 31, August 14, August 28, September 11, and September 24. The plant samples were taken with a spade at random from each plot. The samples included a portion of the root system. Each sample included ten plants.

After taking the samples, each plant was carefully washed and then dried in a forced air oven set for 90° C. After drying the sample was weighed.

On September 24, a special harvest was made of the mature bean plants. The stems, pods, and seeds were separated, dried, and weighed. The weights of the material were then adjusted to the original stand counts on an acre basis.

Plant Nutrient Uptake Studies

In 1965, 1966, and 1967 the bean plants in treatment E (25 pounds per acre of zinc as ZnSO_4) grew as rapidly and yielded as well as the beans on any of the other treatments.

Plant samples were taken from this plot every two weeks. On the first three dates, 50 plants were composited. On the other sampling dates only 25 plants were included in the composited sample.

The composite samples were rapidly rinsed off with well water and immediately afterwards with a dilute (0.001 N) hydrochloric acid solution and rinsed with deionized water.

The individual plants within each sample were then subdivided into the component parts. The subsamples were dried in a forced air oven at 90°C., weighed, and then ground in a Wiley mill. The subsamples were stored in paper bags until they were chemically analyzed.

Laboratory Procedures -- Plant Analysis

After being stored for varying time periods, the subsamples of ground plant tissue were again dried. A one gram sample was wet ashed with nitric and perchloric acid as described by Piper (47) and Chapman (16).

The crystalline residue was dissolved in 0.1 N HCl, filtered through a Whatman No. 3 paper, diluted to 100 millimeters, and then stored for the several chemical determinations.

Nitrogen was determined on oven dried plant material by the microkjeldahl method as outlined by Pierce and Haenisch (48) and modified by Prince (49).

Phosphorus concentrations in the extracts were determined colorimetrically with the chlorostannous-reduced molybdophosphoric blue method as described by Jackson (28).

Potassium contents were evaluated with a Coleman model 21 flame photometer.

Calcium and magnesium levels were established with a

Perkin Elmer model 303 atomic absorption spectrophotometer as described by Doll and Christenson (19).

Copper, iron, manganese, and zinc contents were evaluated with a Perkin Elmer model 303 atomic absorption spectrophotometer.

Laboratory Procedures -- Soil Analysis

Soil samples were collected from the field plots after the bean plants were harvested. Twenty ^{100 g.} crops of soil, to a depth of eight inches, were taken from each plot. They were composited, passed through a two millimeter screen, mixed, and subsampled.

For the pH determination, ten grams of soil were mixed with ten milliliters of water (1:1 ratio). After fifteen minutes the mixture was stirred again, and the pH of the suspension was determined by using a Beckman Zeromatic glass electrode pH meter.

For the zinc determination, five grams of soil were added to fifty milliliters of 0.1 N HCl and agitated for thirty minutes. The mixture was filtered through a Whatman No. 3 filter paper. The filtrate was then stored in a clean bottle until analyzed with a Perkin-Elmer model 303 atomic absorption spectrophotometer.

IV. RESULTS

Field Experiment -- Part I

The soil upon which these experiments were located was known to have a high pH level and the check plots were known to be deficient in zinc.

The pH levels of the soil and the levels of available zinc were determined after the beans were harvested. The pH ranged between 7.6 and 7.8 (Table 1). With these pH values and on this kind of soil, zinc would normally be recommended for the production of field beans.

The levels of available zinc in the soil were also measured on samples taken after the crop was harvested. All of the results were in the medium to low range, but the "no zinc" plots tested lower than any of the other plots. In interpreting these data, it should be remembered that they were obtained after the bean crops had been produced.

TABLE 1. The pH and available zinc in soil on plots in experimental area.

Treatment*	Red Kidney Bean		White Pea Bean	
	pH	Available Zinc ppm	pH	Available Zinc ppm
A	7.7	4.4	7.7	5.1
B	7.8	15.9	7.8	12.5
C	7.7	12.1	7.8	11.2
D	7.8	7.4	7.8	7.2
E	7.6	10.0	7.8	10.0
F	7.7	6.3	7.7	6.8

*A = No zinc

B = 3.0 pounds per acre zinc as banded zinc sulfate

C = 73.5 pounds per acre zinc as a broadcasted zinc residue material

D = 122.5 pounds per acre zinc as a broadcasted zinc residue material

E = 25.0 pounds per acre zinc as broadcasted zinc sulfate

F = No zinc

2. A clinkerlike material supplied by American Zinc Company and labeled AZCO C-10

Visual Observations on Plant Growth

The first sampling occurred 14 days after the beans were planted. At this time a good stand had been established on all of the plots. There was no visible difference between treatments. The red kidney beans averaged 24,430 plants per acre and the white pea beans 64,324 plants per acre. The difference in stand was due in part to the fact that the red kidney bean seed is larger than the white pea bean, and the same planting rate, 50 pounds per acre, was

used.

At 14 days, only the single (simple) blade primary leaves had developed on each of the varieties.

At 28 days, about 5 percent of the simple leaves (primary leaf) had turned to a yellow color, the third true leaf was just forming at the top of the plant, and the cotyledons had dropped from many of the plants.

At this time the white bean plants, growing on the treatment which received no zinc, showed visual zinc deficiency symptoms. The symptoms were more intense on the white beans than on the red kidney beans. The bean plants which had received zinc at the highest rates had a better color and were more vigorous than the plants on other plots.

At 42 days, most of the primary leaves of both varieties had died and fallen from the plants. Flowers on both varieties were evident. As many as seven branches per plant were observed on the white pea bean plants. The red kidney bean plants had fewer and much smaller branches.

At 56 days, the white beans were bearing pods, except the plant growing on the "no zinc" treatments. The red kidney beans growing on all plots were bearing pods at this time.

At 70 days, both varieties of beans growing on the plots which had received zinc began to dry and showed signs of starting to mature. The white beans growing where no zinc had been used still had not developed any flowers.

At 84 days, where zinc had been used most of the leaves had fallen. The white beans were much drier than the kidneys.

On the check plots, the plants were green, well leafed, and were developing a few blossoms.

Dry Matter Accumulations

Dry matter accumulations are considered to be a good indication of growth. The dry weights of ten plants of each variety of beans as affected by both time (age) and the zinc treatments are found in Appendix III and IV. The same information is presented graphically in Figures 1 and 2.

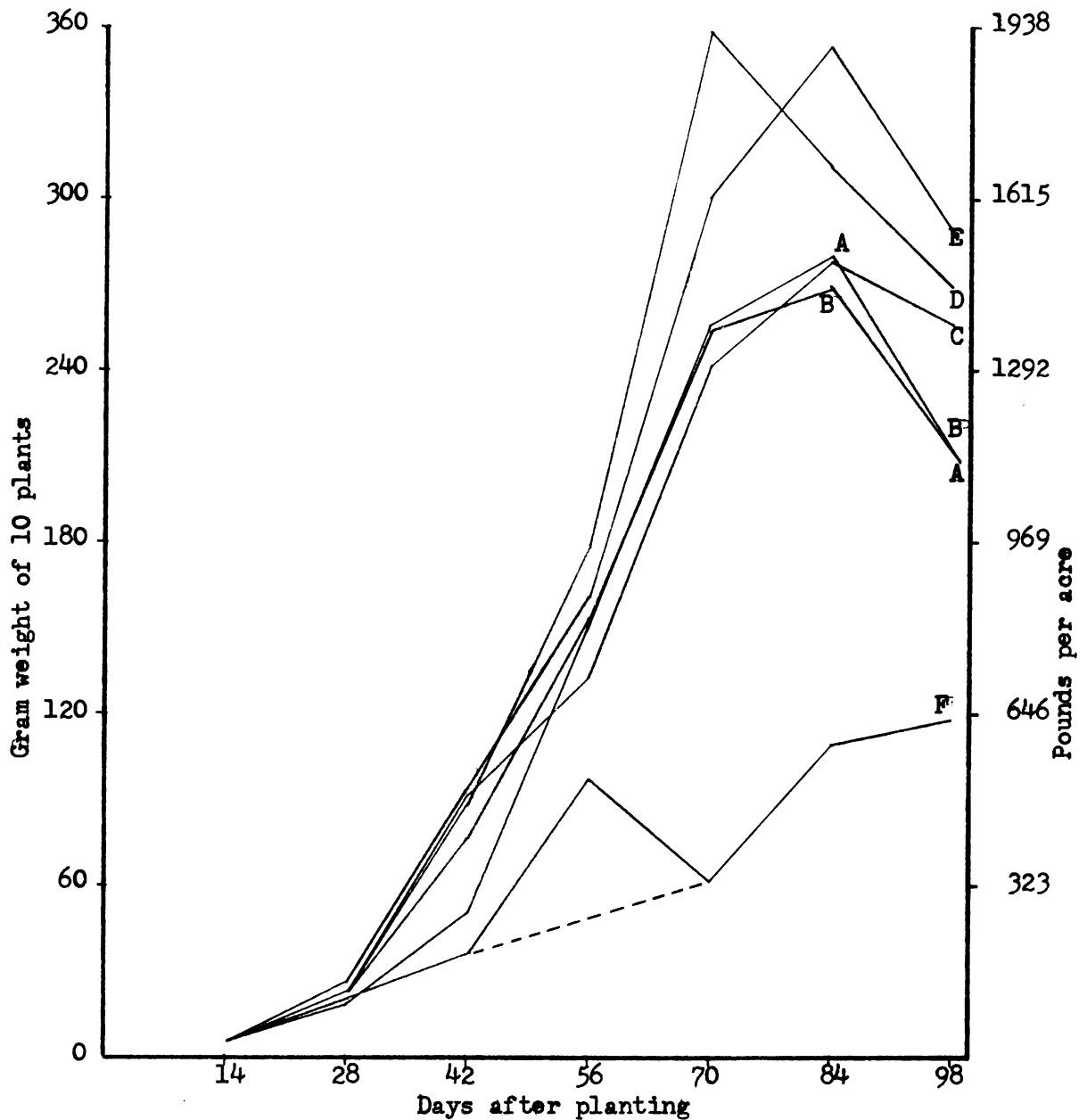
On the first sampling date, only 14 days after planting, each of the zinc treatments had caused a growth response in each of the varieties. Even at this early date the red kidney bean plants weighed approximately twice as much as the white pea bean plants.

At 28 days, except on the check plots where no zinc had been used, the difference between varieties were not so great. Differences caused by zinc containing fertilizer materials were, however, greater than previously measured.

During the third two week period, the rate of dry matter accumulation increased greatly where zinc had been used and on plot A where the red kidney beans were grown even though it had not been treated with zinc. Difference, on a relative basis, between varieties decreased except on the check plots.

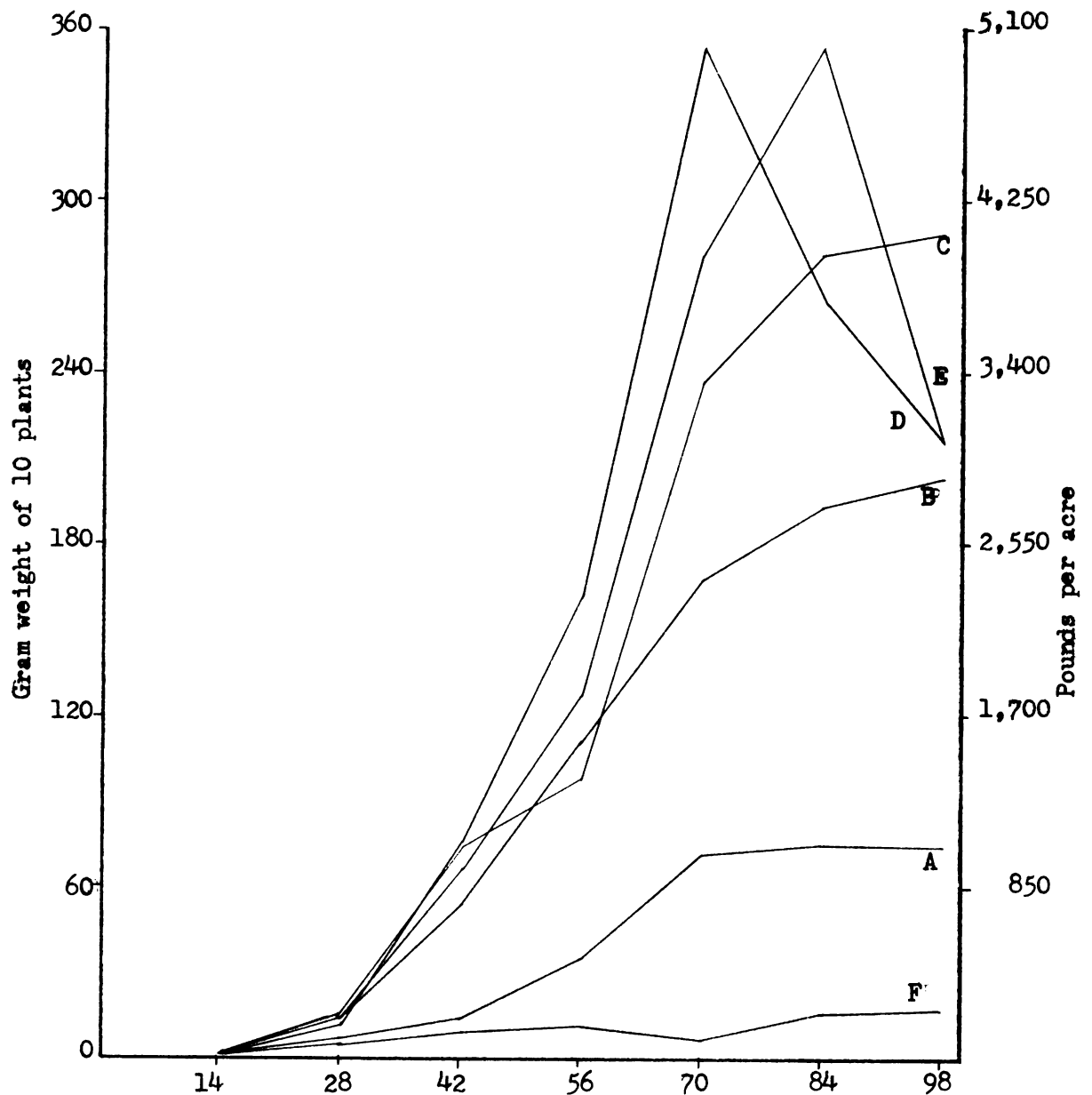
At 56 days, or at the end of the fourth two-week sampling period, the weight of the white pea bean plants where the highest rate of zinc had been used was in excess of the

Figure 1. The dry matter accumulation of the red kidney bean as affected by age and zinc.



- A : No zinc.
 B : 3.0 pounds per acre zinc as banded zinc sulfate.
 C : 73.5 pounds per acre zinc as a broadcasted zinc residue material.
 D : 122.5 pounds per acre zinc as a broadcasted zinc residue material.
 E : 25 pounds per acre zinc as broadcasted zinc sulfate.
 F : No zinc.

Figure 2. The dry matter accumulation of the white pea bean as affected by age and zinc.



- A : No zinc.
 B : 3.0 pounds per acre zinc as banded zinc sulfate.
 C : 73.5 pounds per acre zinc as a broadcasted zinc residue material.
 D : 122.5 pounds per acre zinc as a broadcasted zinc residue material.
 E : 25.0 pounds per acre zinc as broadcasted zinc sulfate.
 F : No zinc.

weight of the red kidney bean plants grown on the same plot. By this time differences between treatments were greater than between varieties of beans.

The most rapid accumulation of dry matter occurred during the fifth two-week period on most of the plots. The plants of both varieties reached their maximum weight in this period on treatment D where 122.5 pounds of zinc, as a zinc residue material, had been plowed down in 1965. On this treatment, after 70 days, the plants of both varieties lost weight due to the loss of leaves as the plants approached maturity.

The red kidney bean plants continued to increase in weight during the next two-week period on all of the plots except F. After 84 days a loss in total weight was observed.

The white pea bean plants grew in a similar manner except where either no zinc or where the lower rate of the two carriers had been used.

At harvest time, most of the red kidney bean plants were still larger than the white pea bean plants, but differences in size were not as great as those observed earlier in the season.

The pounds per acre of maximum dry matter accumulations on the red kidney bean plants are shown in Table 2. These figures represent only approximate total accumulations because at this sampling time, a leaf or two had dropped off of the lower portion of the plants. In all probability, the higher weights shown in this table might have been slightly

larger if it had been possible to collect all of the leaves, such as was done on the plots which received no zinc or on those which received the lower rates of the two carriers.

The highest dry matter accumulation of the red kidney beans occurred on those plots which received the highest rates of zinc.

TABLE 2. The maximum dry matter accumulation of red kidney and white pea beans as affected by zinc

Treatment Letter*	Red Kidney Bean		White Pea Bean	
	Age Days	Dry Matter Pounds per Acre	Age Days	Dry Matter Pounds per Acre
A	84	1507	84	1065
B	84	1452	98	2903
C	84	1501	98	4090
D	70	1933	70	5027
E	84	1806	84	5013
F	98	637	98	272

* A = No zinc

B = 3.0 pounds per acre zinc as banded zinc sulfate

C = 73.5 pounds per acre zinc as a broadcasted zinc residue material

D = 122.5 pounds per acre zinc as a broadcasted zinc residue material

E = 25.0 pounds per acre zinc as broadcasted zinc sulfate

F = No zinc

Despite the fact that an apparent response to zinc was obtained with red kidney beans, the dry-matter accumulations were low and did not represent a satisfactory growth condition for this crop during the 1968 season. Care should be exercised, in interpreting these data for other environments.

The same kind of information for the white pea beans is also shown in Table 1. These data are considered to be more typical of the average dry-matter production in Michigan where no significant zinc deficiency occurs. The greatest accumulation of dry matter occurred on those plots which received the largest amount of zinc (122.5 pounds per acre of zinc). Dry matter production was in excess of 2½ tons per acre on some of the plots that received zinc but dropped to a low of only 272 pounds per acre on one of the "no zinc" plots.

The Average Number of Leaves per Plant

The average number of leaves per plant obtained from the various treatments are shown in Table 3. The differences in number of leaves on the red kidney beans was small, but great for white beans. The treatment which received zinc at the rate of 25 pounds per acre as zinc sulfate gave the highest number of leaves per plant for both varieties.

Both varieties produced the lowest number of leaves where no zinc was added.

The average number of leaves was greater on the white pea bean than on the red kidney bean plants on all plots.

TABLE 3. The Average Number of Leaves per Plant as Affected by Zinc (56 Days after Planting)

Treatment Letter*	The Number of Leaves per Plant	
	Red Kidney Beans	White Pea Beans
A	15.0	17.0
B	15.3	23.9
C	14.9	20.8
D	15.1	26.0
E	16.2	26.0
F	12.3	13.2

* A = No Zinc

B = 3.0 Pounds per Acre Zinc as Banded Zinc Sulfate

C = 73.5 Pounds per Acre Zinc as a Broadcasted Zinc Residue Material

D = 122.5 Pounds per Acre Zinc as a Broadcasted Zinc Residue Material

E = 25.0 Pounds per Acre Zinc as Broadcasted Zinc Sulfate

F = No Zinc

The Average Number of Pods per Plant

The effect of zinc upon the production of pods is shown in Table 4. The use of zinc on this deficient soil increased the number of pods on both varieties, and the increase was greatest on the white pea beans.

TABLE 4. The Average Number of Pods per Plant as Affected by Zinc

Treatment Letter*	The Number of Pods per Plant	
	Red Kidney Bean	White Pea Bean
A	9.6	10.1
B	8.2	19.0
C	9.9	22.2
D	10.1	19.5
E	12.2	20.4
F	5.1	1.3

* A = No Zinc

B = 3.0 Pounds per Acre Zinc as Banded Zinc Sulfate

C = 73.5 Pounds per Acre Zinc as a Broadcasted Zinc Residue Material

D = 122.5 Pounds per Acre Zinc as a Broadcasted Zinc Residue Material

E = 25.0 Pounds per Acre Zinc as Broadcasted Zinc Sulfate

F = No Zinc

The Average Number of Seeds per Pod

The use of zinc slightly increased the number of seeds per pod on the red kidney beans and greatly increased the number on the white pea bean plants. The differences caused by the carriers and rates of zinc were not of a sufficient magnitude to believe that these differences are significant.

TABLE 5. The Average Number of Seeds per Pod as Affected by Zinc

Treatment Letter*	The Number of Seeds per Pod	
	Red Kidney Beans	White Pea Beans
A	2.9	1.8
B	3.7	3.7
C	4.1	4.2
D	3.7	4.4
E	3.6	4.0
F	2.9	0.0

A = No zinc

B = 3.0 pounds per acre zinc as banded zinc sulfate

C = 73.5 pounds per acre zinc as a broadcasted zinc residue material

D = 122.5 pounds per acre zinc as a broadcasted zinc residue material

E = 25 pounds per acre zinc as broadcasted zinc sulfate

F = No zinc

Seed Yields

The red kidney bean seed yields were disappointingly low. Treatment F, which was a "no zinc" treatment, yielded only ^{4.9}~~2.9~~ bushels per acre. Treatment A, the other "no zinc" treatment, yielded almost double that produced on F. This reflects an ability of this plot to supply more native zinc. The zinc treatments B, C, D and E yielded slightly more than treatment A (Table 6).

The white pea bean yields where zinc was used were

TABLE 6. The yield of seed as affected by zinc

Treatment Letter*	Bushels Per Acre	
	Red Kidney Beans	White Pea Beans
A	9.5	5.0
B	10.1	25.7
C	12.8	37.7
D	12.2	30.0
E	14.0	38.6
F	4.9	0.0

* A = No zinc

B = 3.0 pounds per acre zinc as banded zinc sulfate

C = 73.5 pounds per acre zinc as a broadcasted zinc residue material

D = 122.5 pounds per acre zinc as a broadcasted zinc residue material

E = 25.0 pounds per acre zinc as broadcasted zinc sulfate

F = No zinc

considerably higher than the red kidney bean yields. The two "no zinc" plots yielded less. This indicates that either the white pea beans have a higher zinc requirement or that they do not have the ability to extract adequate amounts of zinc from the soil.

Laboratory Studies Part II

The purpose of the laboratory studies was to evaluate the growth rate as well as the nutrient composition and uptake of the several parts of both red kidney and white pea bean plants.

The data in this section were obtained from one plot (Treatment E) which in previous years had produced white pea beans as well as or better than any of the other plots. The first time red kidney beans had been grown on these plots was in 1968.

From previous discussions, it should be evident that the data representing the white pea beans are the more significant in that the yields produced more nearly represent those produced by the commercial bean farmer.

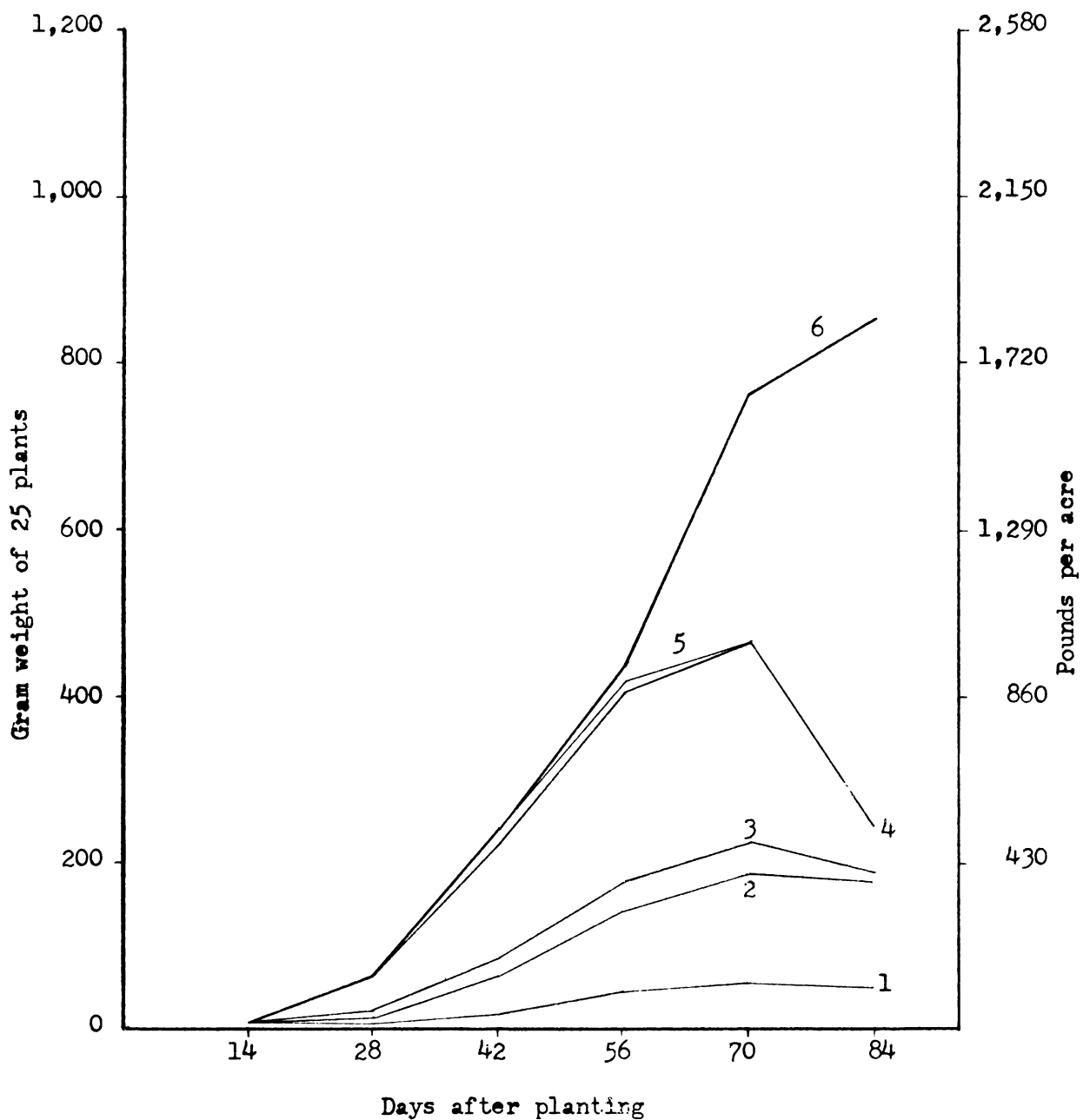
In considering the following data, it should be recognized that every attempt possible was made to create a desirable environment for the production of beans. As far as is known, not a single soil nutrient should have been deficient from Treatment E. Recommended varieties of beans were grown, and they were planted on time with the best available seed. Weeds were well controlled. Temperature and water were the only factors not well regulated. Therefore, the data that were collected were expected to represent an environment well suited for the production of high yields.

The Growth Rate of Parts of the Bean Plant

The growth rates of the several parts of both the red kidney bean and the white pea bean are shown in Figures 3 and 4. The raw data used as a basis for these figures are in Appendix Tables V, VI, VII and VIII.

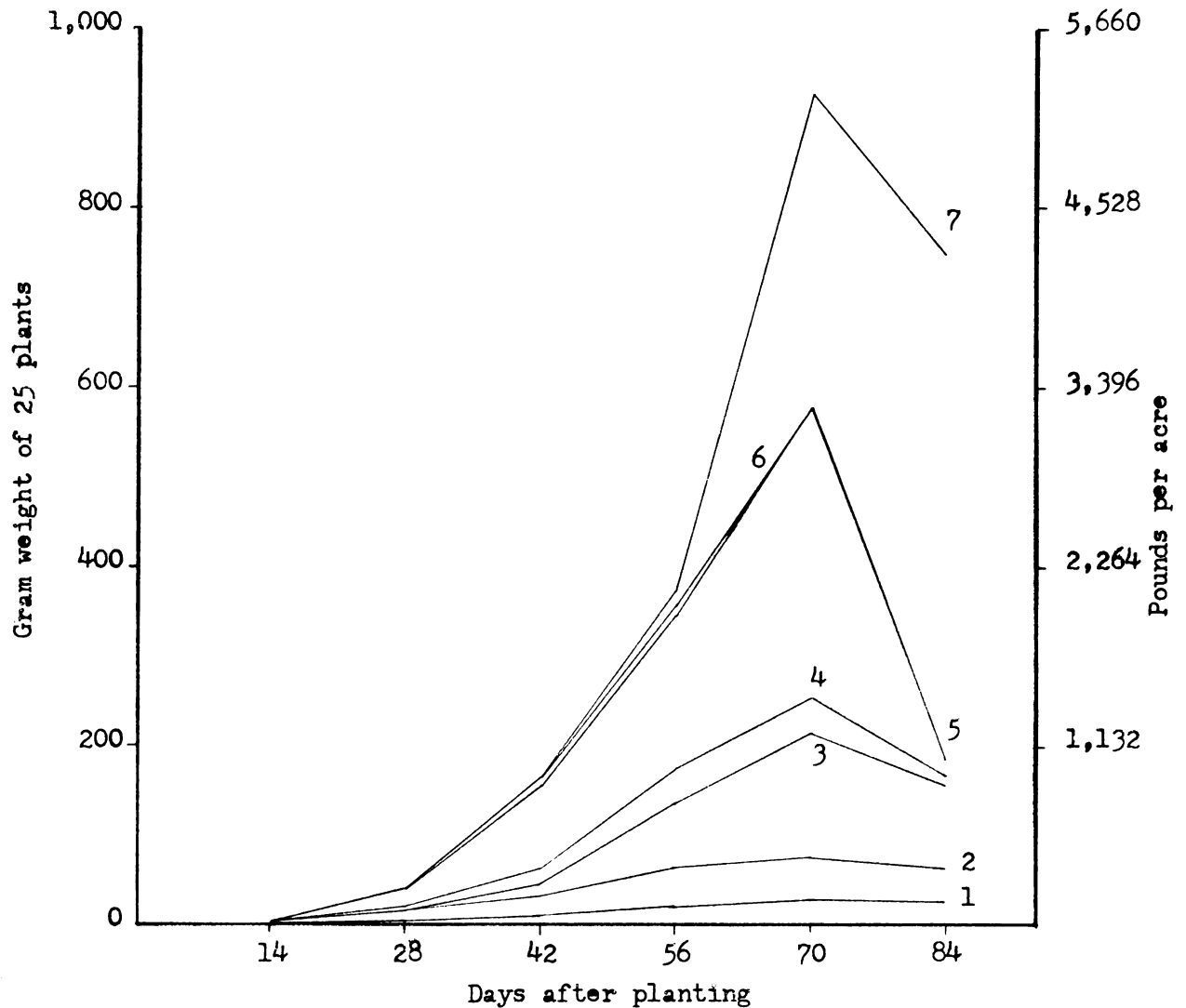
The rate of dry matter accumulation (growth) of the several parts of the red kidney bean plants varied greatly.

Figure 3. The accumulation of dry matter during the growth of red kidney beans.



- 1 : Rootstub.
- 2 : Rootstub + stem.
- 3 : Rootstub + stem + petiole.
- 4 : Rootstub + stem + petiole + leaf blade.
- 5 : Rootstub + stem + petiole + leaf blade + flower.
- 6 : Rootstub + stem + petiole + leaf blade + flower + pod.

Figure 4. The accumulation of dry matter during the growth of white pea beans.



- 1 : Rootstub.
- 2 : Rootstub + stem.
- 3 : Rootstub + stem + branch.
- 4 : Rootstub + stem + branch + petiole.
- 5 : Rootstub + stem + branch + petiole + leaf blade.
- 6 : Rootstub + stem + branch + petiole + leaf blade + flower.
- 7 : Rootstub + stem + branch + petiole + leaf blade + flower + pod.

The rate of dry matter accumulation of the root stubs, stems and petioles increased slowly as the plant approached the mature stage and the rate of dry-matter accumulation of the leaf blades and pods increased rapidly at the stage labeled 28 days after planting. The dry weight of all plant parts except the pods decreased after 70 days. The decreased in root and stem weights is not considered to be significant. The greatest dry-matter accumulation was in the pod which represented nearly one half of the weight of the entire plant.

The rate of dry-matter accumulations in the various parts of white pea beans varied greatly with plant parts and the stages of growth. The rate of accumulation of dry matter of the root-stubs, stems and petioles increased slowly as the plant approached the mature stage, but the rate of dry matter accumulation of leaf blades and pods increased rapidly after 28 days and decreased some after the age of 70 days. The reason for a decrease in pod weight at 84 days is not evident, unless in the harvest process some pods shattered and some seed was lost. The dry matter accumulation of pods and leaf blades was greater than in any other parts of the bean plants. Small quantities were found in the flowers.

The total dry-matter accumulations of both bean varieties were similar before the age of 70 days but somewhat different after this time. Rate of dry-matter accumulation in the red kidney beans increased more rapidly than in the white pea beans. However, the total dry matter accumulation

on an acre basis of white pea beans was greater than in the red kidney beans.

In Figures 3 and 4, it is evident that some loss in weight was obtained in the petiole and leaf blade portion of the plants. This was due primarily to leaves being lost between sampling periods. This is a natural occurrence during the maturation of a bean plant. Also, a few bean seeds were lost while harvesting the crop. Even though care was taken, it was impossible to keep some pods from shattering during harvest.

In the following section on nutrient uptake by bean plants, the graphs do not include information from the last (84 days) tissue collection period because in actuality the plant lost nutrients in the maturation process.

The nutrient content of the several parts of the two varieties of bean plants are shown in Tables 9-26 in the Appendix, primarily because the data represent the movement of nutrients in the plant during the growing season. The data hopefully will be more useful in the future. At the present time, the nutrient level of a single portion of a plant has little practical significance.

Nitrogen Content and Uptake of Bean Plants

The nitrogen content, expressed on a "percent" basis, of the several parts of the red kidney bean plant at six stages of growth is shown in Appendix IX. The percent of nitrogen varied from 0.52 percent to 6.07 percent.

The percent nitrogen in the stem decreased with time from 4.80 to 1.18. The cotyledon contained a relatively

high concentration of 2.2 percent at 14 days. The cotyledon had dried or dropped off by the second sampling.

The concentration of nitrogen in the leaf blade was always higher than in the leaf petiole. With time, the percent nitrogen in both parts of the leaf tended to decrease. The new leaves that formed when the plant was almost mature were very low in nitrogen.

Small and young seed pods contained a relatively high concentration of nitrogen, up to 4.35 percent. As the pod developed and contained seed, the nitrogen content of the shell decreased while the content of the seed increased.

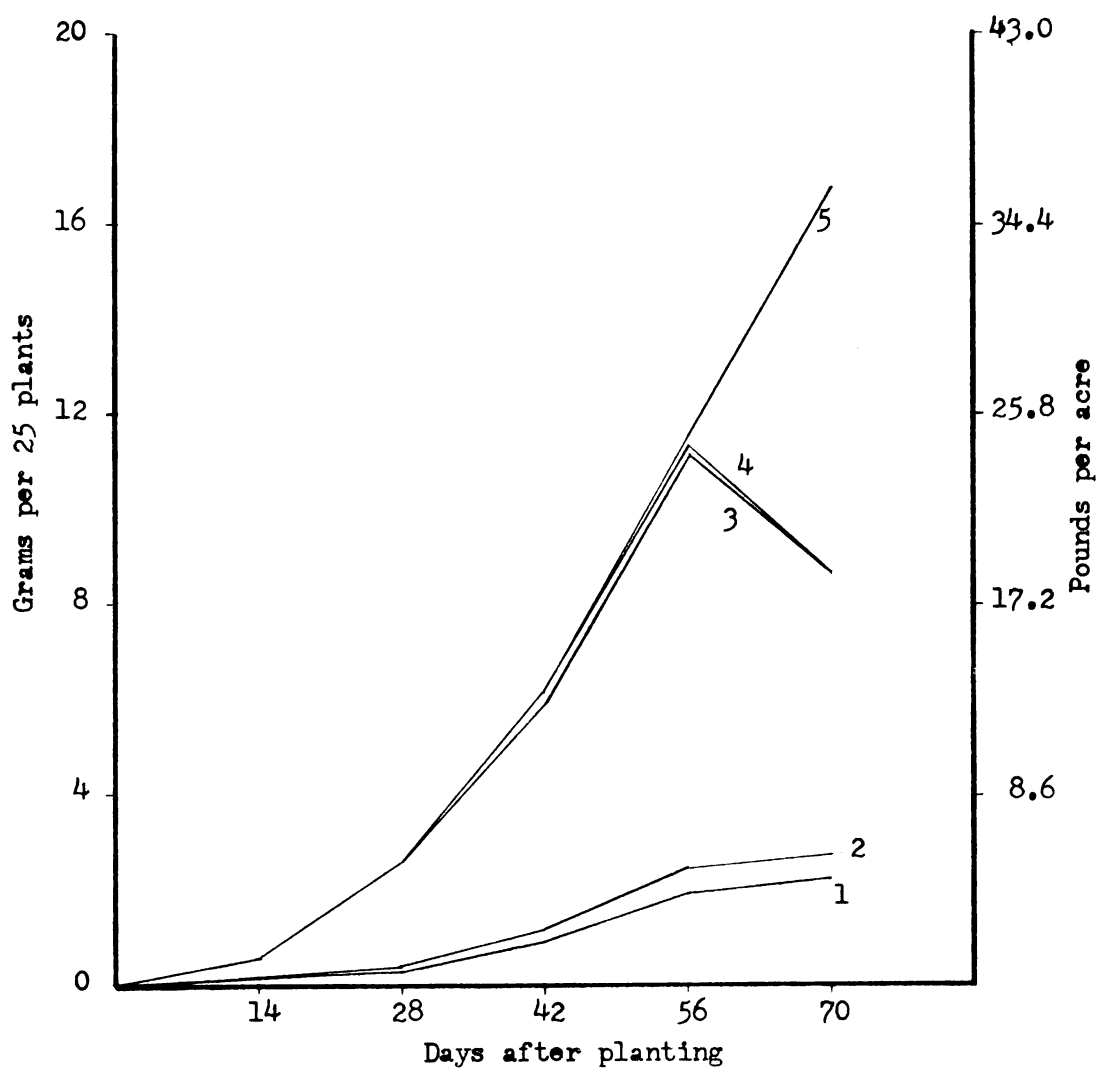
The same information for the white pea beans is shown in Appendix X. In general, the same results were obtained except that the values tended to be somewhat lower. Also the range was narrower, varying from 0.77 percent to 6.01 percent.

The uptake of nitrogen by the red kidney bean plant is shown in Figure 5.

The nitrogen uptake by red kidney beans varied during the growing season and with plant parts. The rate of nitrogen uptake in the entire plant increased rapidly after 28 days from planting. The largest amounts of nitrogen accumulated in the leaf blade. The smallest amount was in the flowers.

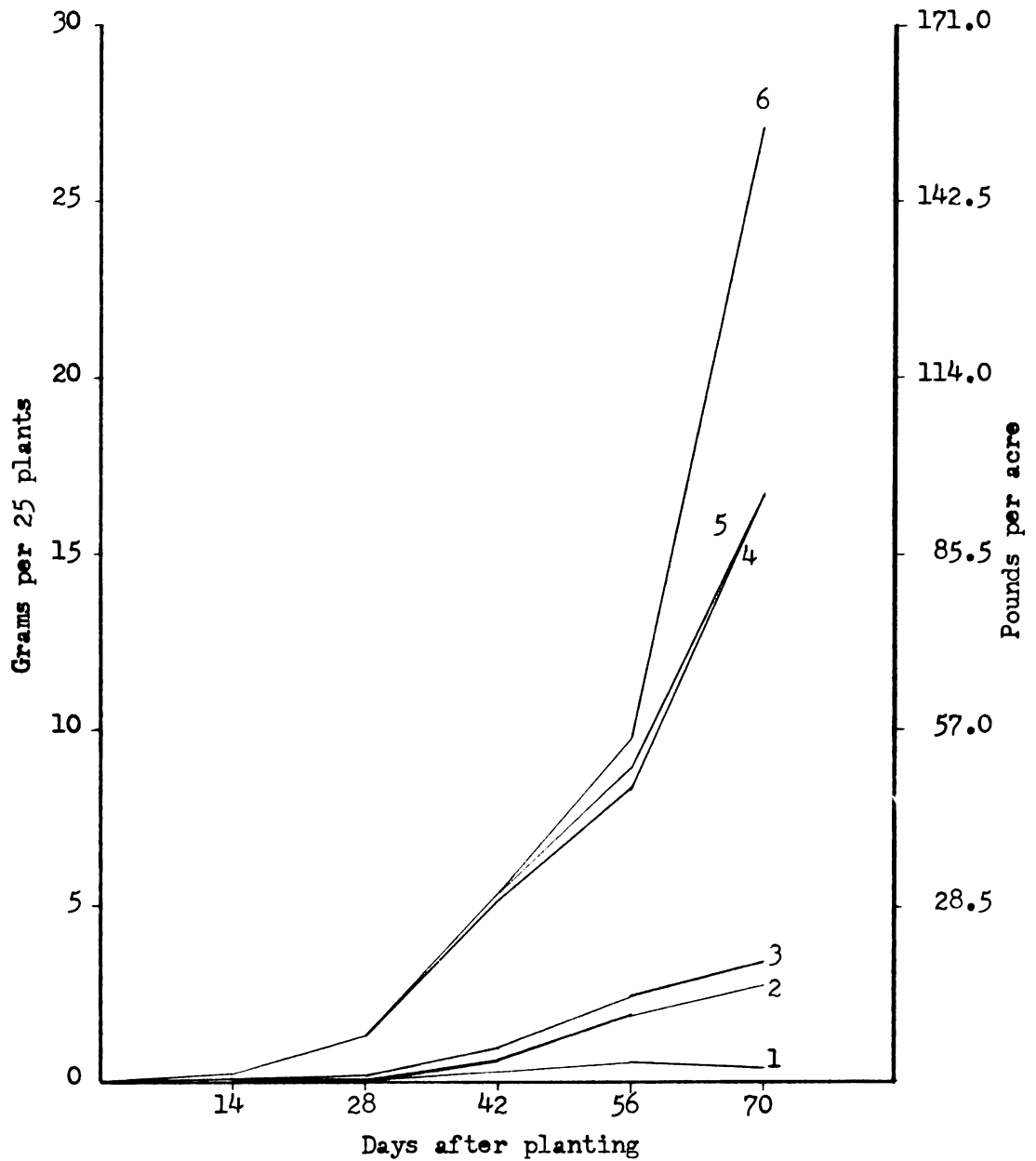
The nitrogen accumulations for the white pea beans are shown in Figure 6. The accumulation rate was somewhat slower than with the kidney beans but rose to a higher level due primarily to a higher seed yield.

Figure 5. The nitrogen uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 6. The nitrogen uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

Phosphorus Content and Uptake of Bean Plants

The phosphorus content, expressed on a percent basis of the several parts of the red kidney bean plant at six stages of growth is shown in Appendix XI.

The concentration of phosphorus within the red kidney bean plant varied from 0.06 percent to 0.70 percent. In general, the concentration of phosphorus decreased with age of the plant part. For example, the stem decreased from 0.55 percent phosphorus at two weeks to 0.07 percent at 12 weeks (84 days).

At 14 days the cotyledon was wrinkled but contained 0.23 percent phosphorus. At 28 days the cotyledon had dried and fallen from the stem.

The petiole and the blade of the primary leaf contained approximately equal amounts of phosphorus during the first two sampling dates. On the third date (42 days) the blade contained more phosphorus than the petiole. The concentration of phosphorus decreased with time in both the petiole and blade.

On the 28-day sampling period, the phosphorus content of the first three "true" leaves varied with the position of the leaf or with time of formation. Moving up the plant, the phosphorus in the petiole decreased from 0.41 to 0.16 percent while the content of the blade increased from 0.41 to 0.57 percent.

The phosphorus in the immature pod decreased as the seed developed. It apparently moved directly from the pod into the seed and then as the seed matured, the concentration

decreased as in the pod. This probably was little more than a dilution factor.

The same kind of data for the white pea bean is shown in Appendix XII. Although there were exceptions, many of the values tended to be somewhat lower for the white pea beans. The values ranged from 0.04 to 0.83 percent, depending upon the part of the plant sampled and the time the samples were taken.

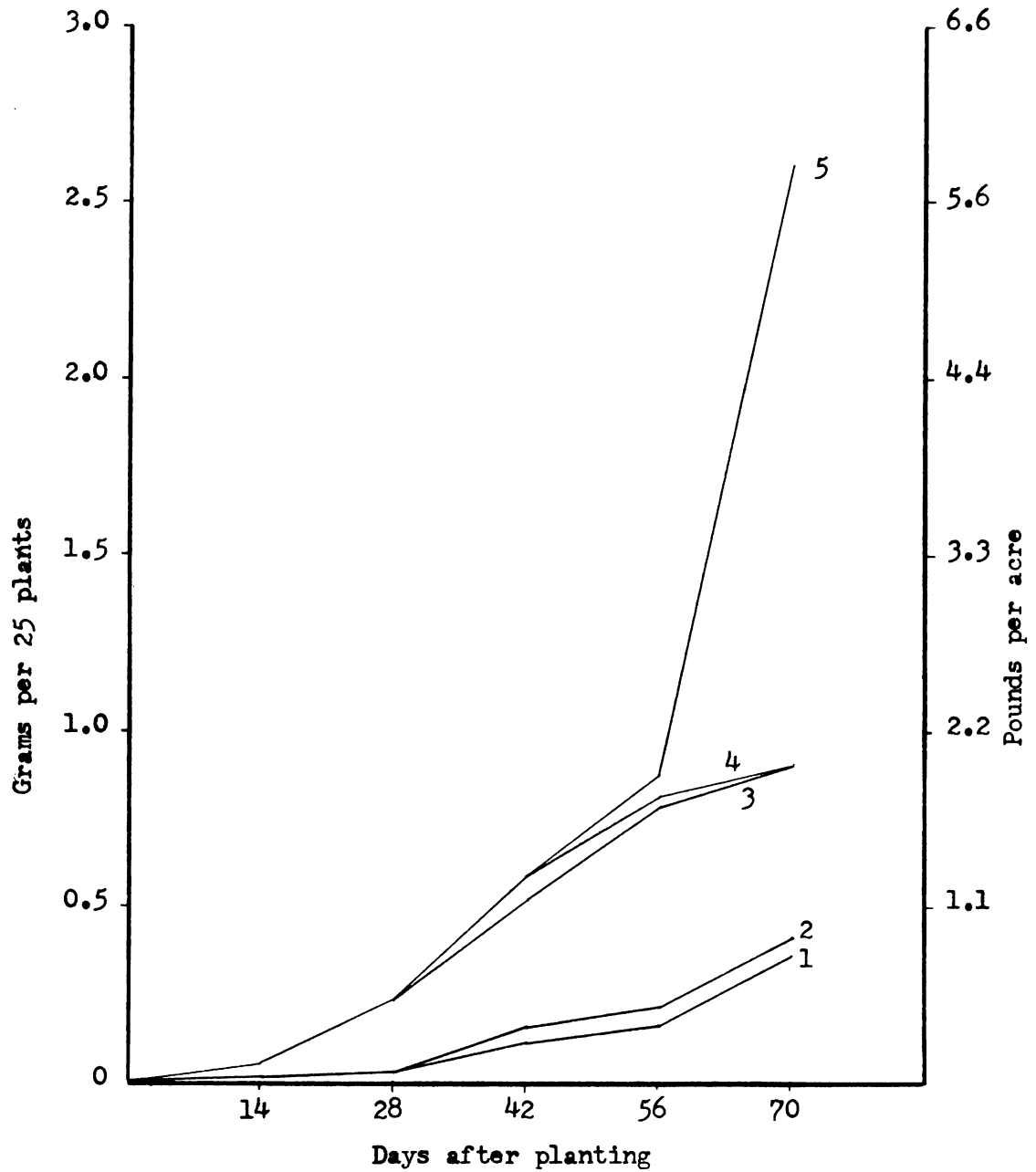
In general, the same trends in concentration of phosphorus were found in the white pea beans. The one exception that is evident is that the phosphorus content of the petiole of the true leaves did not decrease as the age of the leaf decreased. As in the red kidney beans, the phosphorus content of the leaf blade did decrease as the age of the leaf increased.

The uptake of phosphorus by the red kidney bean is shown in Figure 7. On an acre basis, the values are exceptionally low due to the fact that the plots had a relatively low population. As with nitrogen, the phosphorus was found primarily in the leaf blades and in the pods.

Similar data for the white pea beans are shown in Figure 8.

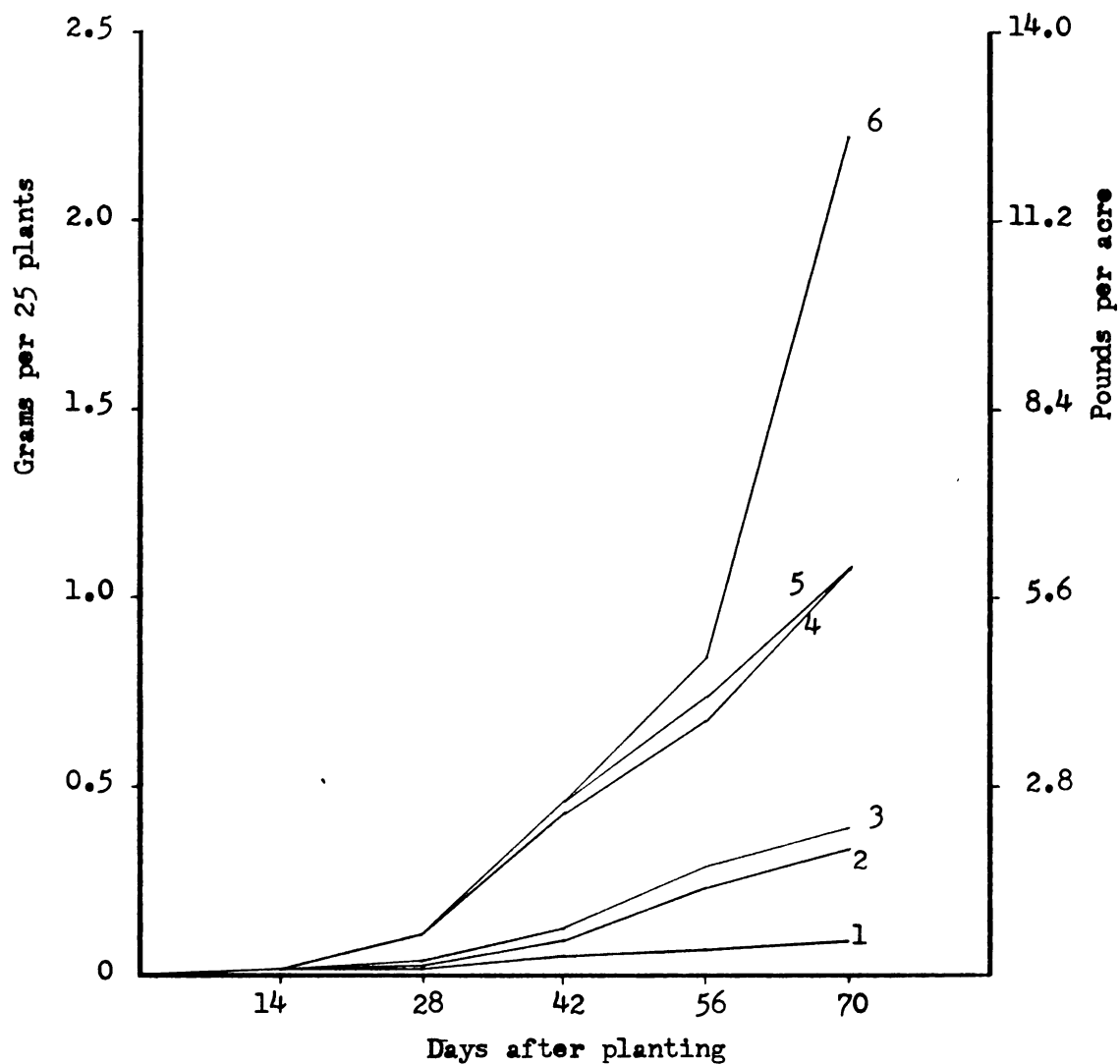
The curves showing the phosphorus uptake by several parts of the plant are similar to those already discussed. The major difference is expressed on an acre basis. While the phosphorus uptake by individual plants of the two varieties were similar, the uptake on an acre basis by the white pea bean was considerably greater due to the higher population.

Figure 7. The phosphorus uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 8. The phosphorus uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

population.

Potassium Content and Uptake of Bean Plants

The potassium content of the red kidney bean plants is shown in Appendix XIII. The percent potassium varied from a low of 0.30 percent in the blade of the older leaves to 6.5 percent in the petiole of the first formed true leaf.

As with nitrogen and phosphorus, the concentration of potassium in the stem decreased with time. The cotyledon contained a very small amount, only 0.65 percent at the time of the first sampling. The potassium content of both the petiole and the blade of the primary leaf varied with sampling time.

In general, the potassium was most concentrated in the new fully-developed tissue. As the tissue became older, the potassium level tended to decrease. This is illustrated by the potassium content of the petiole of the first true leaves which decreased from 6.50 percent potassium in the lower leaf to 2.27 percent in the upper leaf. The decrease was not as great in the blades of these leaves. After a certain stage of maturity was attained, the older leaves dropped in levels of potassium. The level in pods and seed were relatively low, averaging approximately two percent.

The potassium levels in the white pea bean are shown in Appendix XIV. While the potassium levels seemed to fluctuate more than in the red kidney beans, the same general trends prevailed. The potassium concentration ranged from 0.40 percent in the cotyledon to 6.00 percent in the petiole

of the second true leaf which was sampled at 28 days of growth.

The accumulation of potassium within the red kidney bean plant is shown in Figure 9. The curves, except being expressed on a different scale, are similar to those described for nitrogen. Again the leaf blade and the pod contained the greatest amount of potassium. The branches from the main stem also contained relatively large amounts.

The total uptake of less than 25 pounds per acre of potassium was lower than anticipated. This value is slightly misleading in that it does not recognize the loss of some leaves.

The uptake of potassium by the white pea bean plant was closer to the values expected for legumes (Figure 10). The value of 85 pounds reflects the maximum accumulation of all parts of the plant.

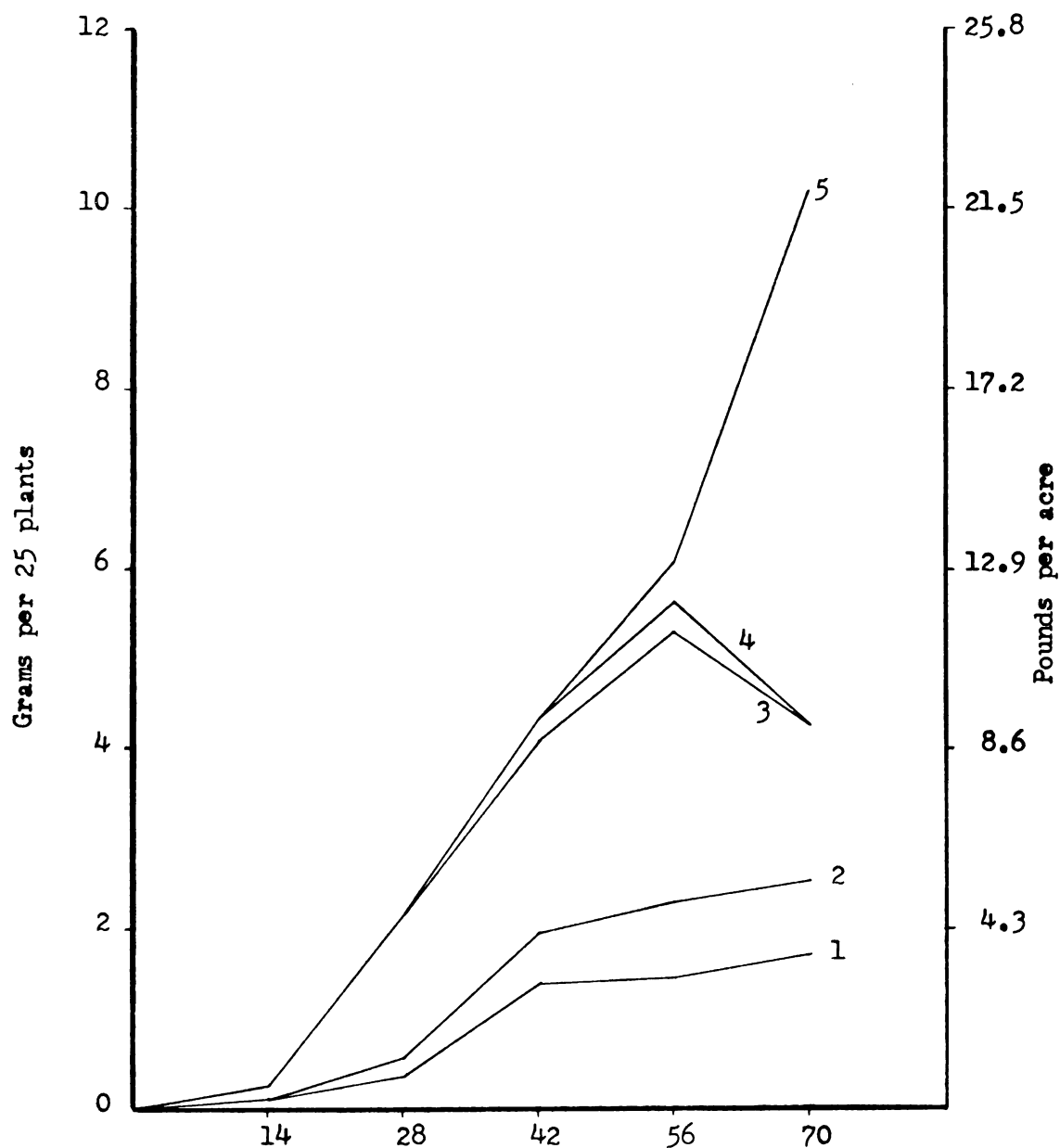
Calcium Content and Uptake of Bean Plants

Because of high pH levels, calcium was not expected to be deficient in the soil used for this experiment. The concentration of calcium within the several parts of the red kidney bean plant is shown in Appendix XV.

The calcium content ranged from a low of 0.08 percent to a high of 5.83 percent. The concentration of calcium in the leaf blade was always higher than in the petiole.

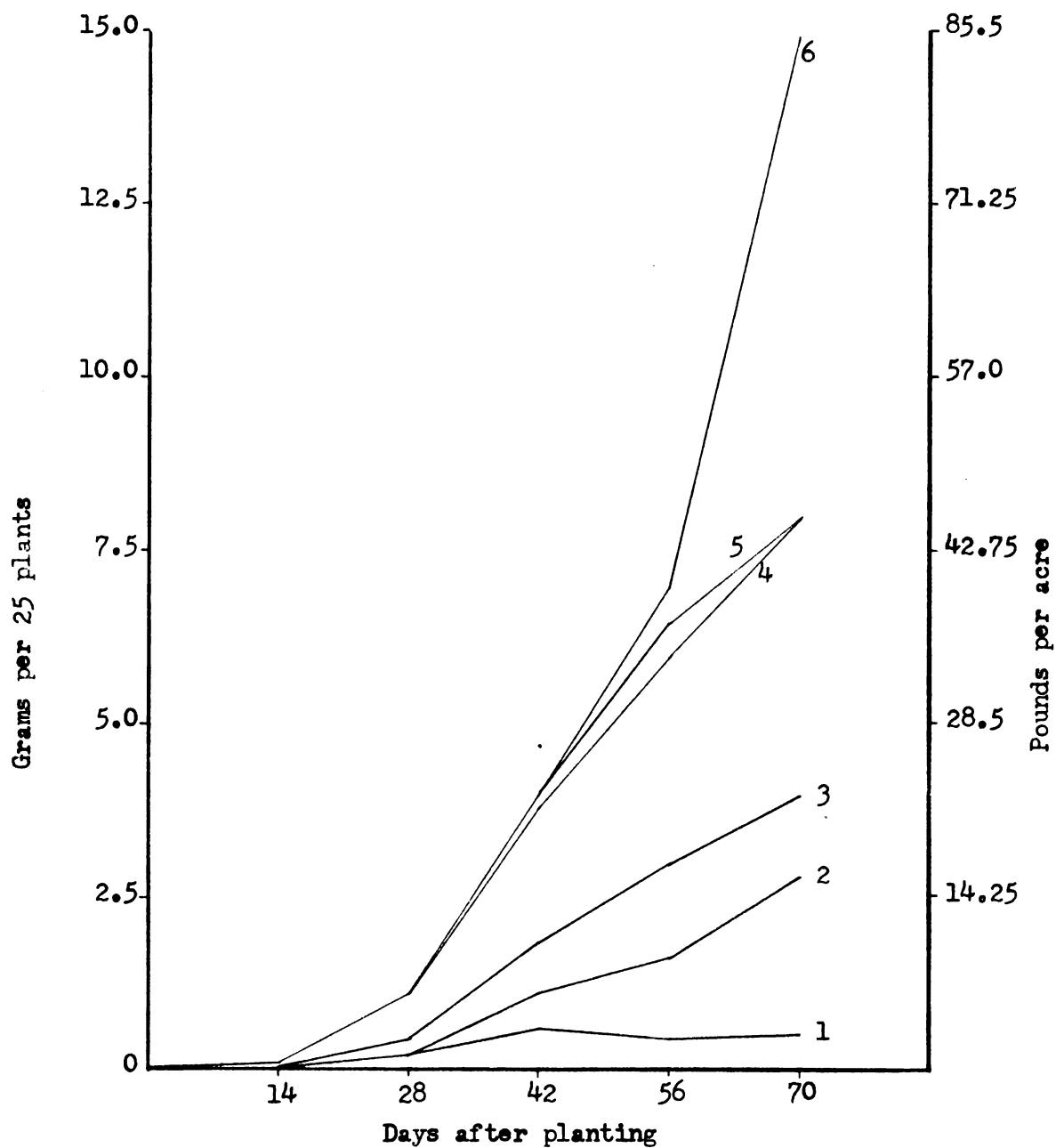
In contrast with the nutrients already considered, the calcium content of the stem increased with time from 0.86 to 1.48 percent. This same trend was also evident in the other

Figure 9. The potassium uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 10. The potassium uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

parts of the plant.

The seed contained only 0.14 percent calcium. The level in all other parts of the plant, except the petiole of the lower leaf contained higher concentrations than did the seed.

Similar information on the white pea bean is shown in Appendix XVI. While the same trends in uptake of calcium are present, the data are more difficult to interpret due to variations in calcium content from one sampling time to another. No explanation for this situation is offered.

The uptake of calcium by the two bean varieties is shown in Figures 11 and 12. In both varieties, most of the calcium was concentrated in the leaf blades. The uptake was most rapid after one month of growth. The calcium uptake in the white pea bean was almost three times that in the red kidney bean.

Magnesium Content and Uptake of Bean Plant

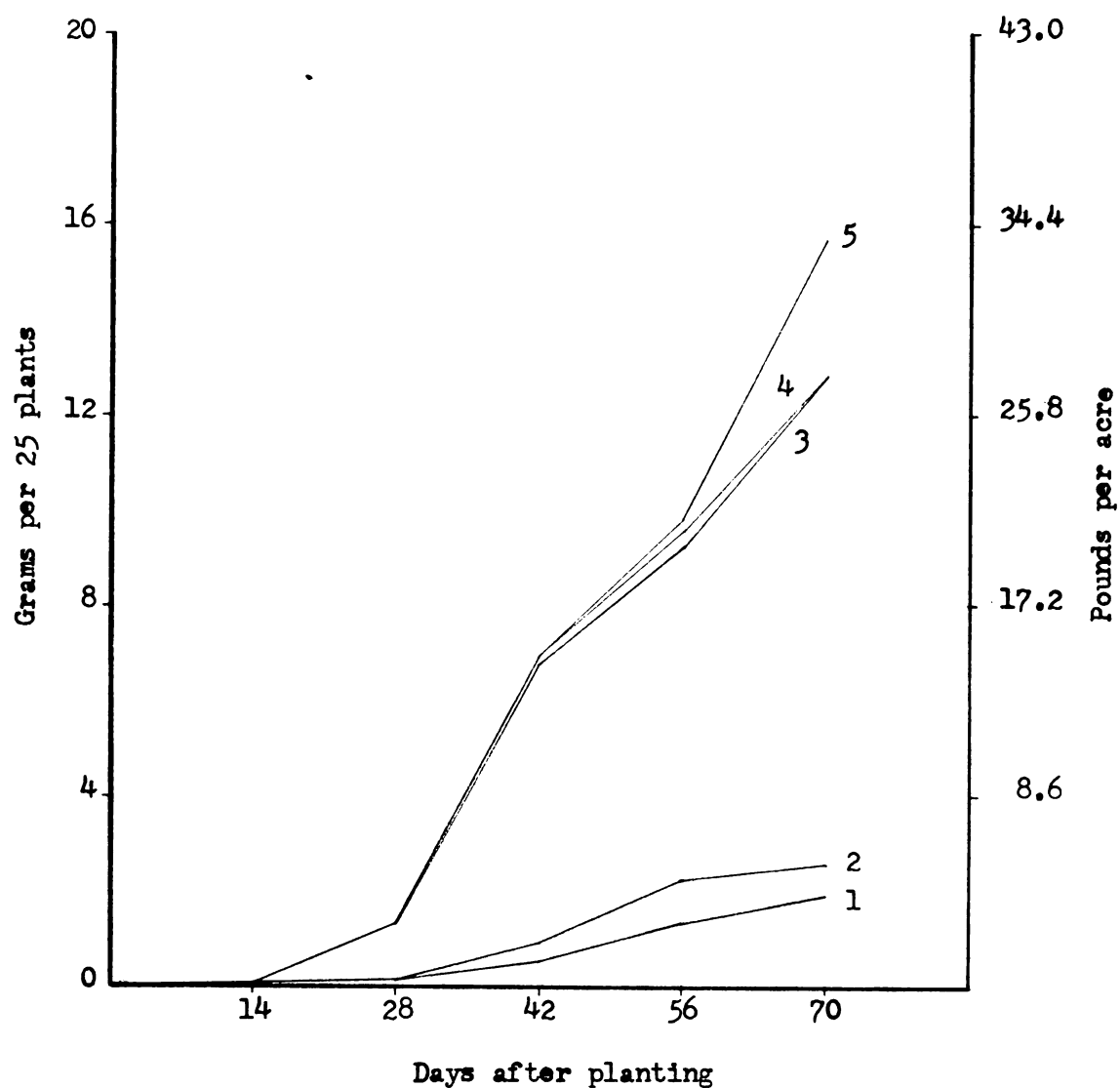
The magnesium content of the red kidney bean is shown in Appendix XVII. The percent in the stem tended to increase with time ranging between 0.34 and 0.47 percent.

The percent magnesium in the petiole of the leaves was always lower than in the blade. The older leaves contained more magnesium than the younger leaves.

The content of the immature pods and the shell of the more mature pods averaged a little less than one half percent. The seed contained less magnesium than the pod.

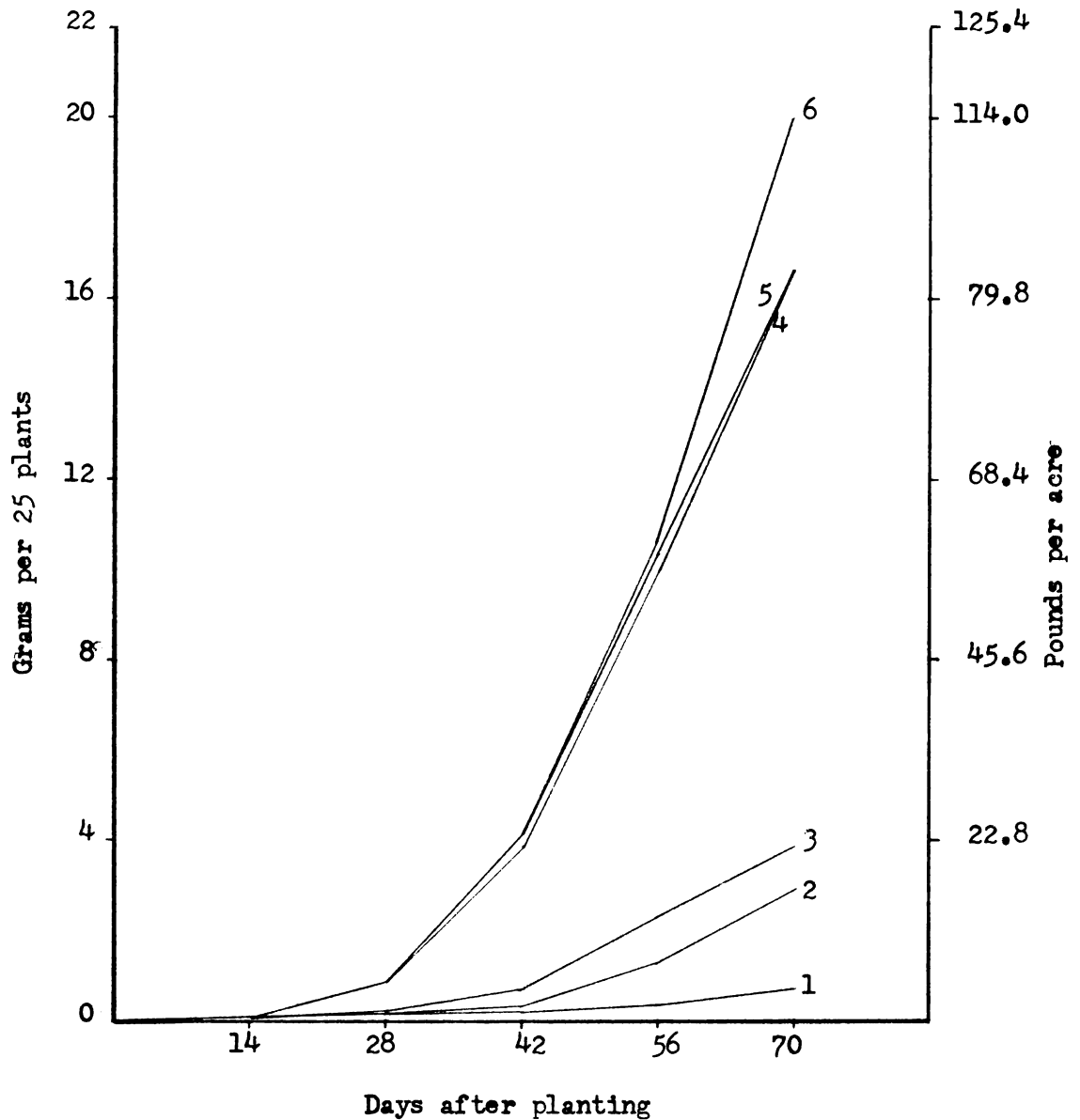
Similar figures for the white pea bean are shown in

Figure 11. The calcium uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 12. The calcium uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

Appendix XVIII. The magnesium content of the stem increased with age from 0.52 percent to 0.69 percent. The percent magnesium contained in the branches also increased with time. The younger branches tended to contain less magnesium than the older and the petioles contain less magnesium than the blades of the leaves.

The uptake of magnesium by the two varieties are shown in Figures 13 and 14. This element accumulated in the stem at relatively slow and uniform rate. The petiole of the leaves accumulated magnesium most rapidly during the fourth two-week period. Most of the magnesium was located in the blade tissue of the leaves. The pods contained the second largest amount of magnesium.

The Copper Content and Uptake by Bean Plants

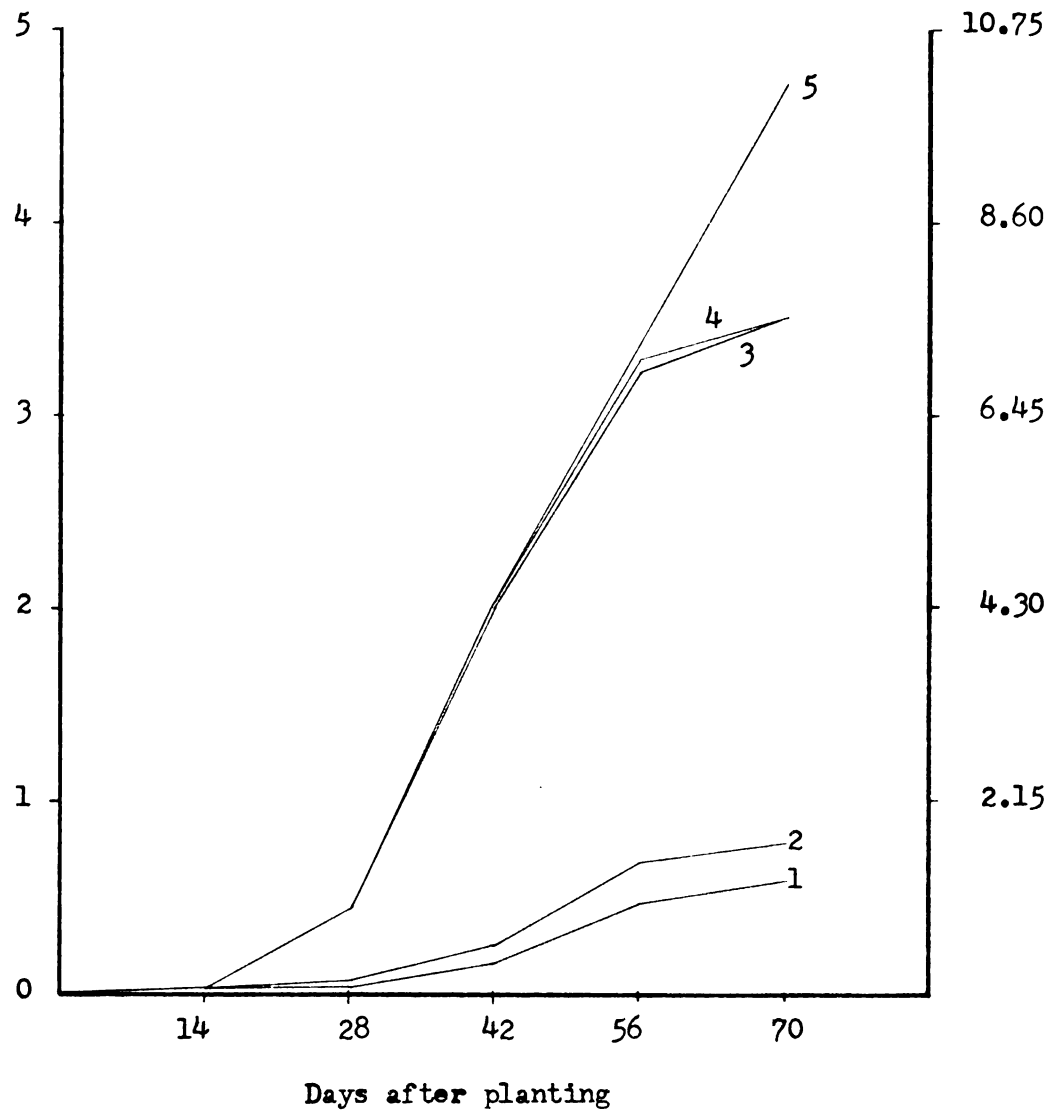
The copper content of the red kidney bean is shown in Appendix XIX.

The copper content of the red kidney bean varied from 5.0 ppm in the shell of mature pods to 32.5 ppm in the blade of small newly formed leaves. The copper content of petioles tended to be higher than the mature leaf blades. The copper concentration of leaf blades varied greatly during the growing season and the copper content of the various parts of the bean plant were generally higher during pod formation.

Similar information for the white pea bean is shown in Appendix XX.

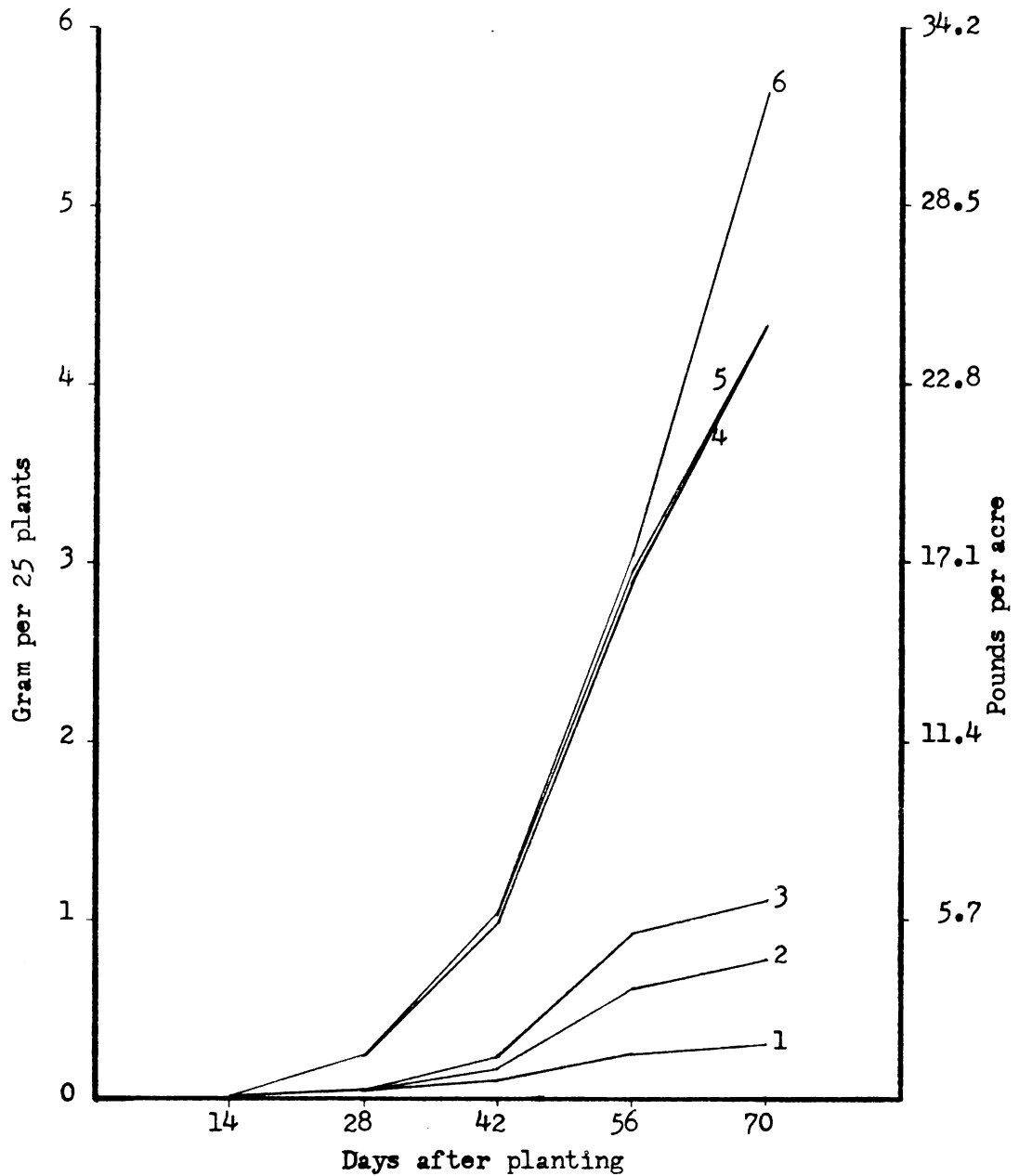
The copper content of white bean plants ranged from 3.3 ppm to 26.8 ppm. This is less than determined in the red

Figure 13. The magnesium uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 14. The magnesium uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

kidney bean. The copper content of the leaf blade was higher than the petiole immediately before flowering, but lower during pod formation. The copper content in several plant parts was relatively high during pod formation.

The uptake of copper by the red kidney bean is shown in Figure 15. As with the other elements, copper uptake was not the same in all parts of the plant. The uptake rate increased rapidly after 28 days especially in the leaf blades. The copper accumulations in the pods and the leaf blades were greater than in any other parts of the bean plant. The smallest quantity of copper was in the flowers. Only a little in excess of 0.02 pounds of copper per acre accumulated in the plants.

Similar uptake patterns were observed in the white pea bean (Figure 16).

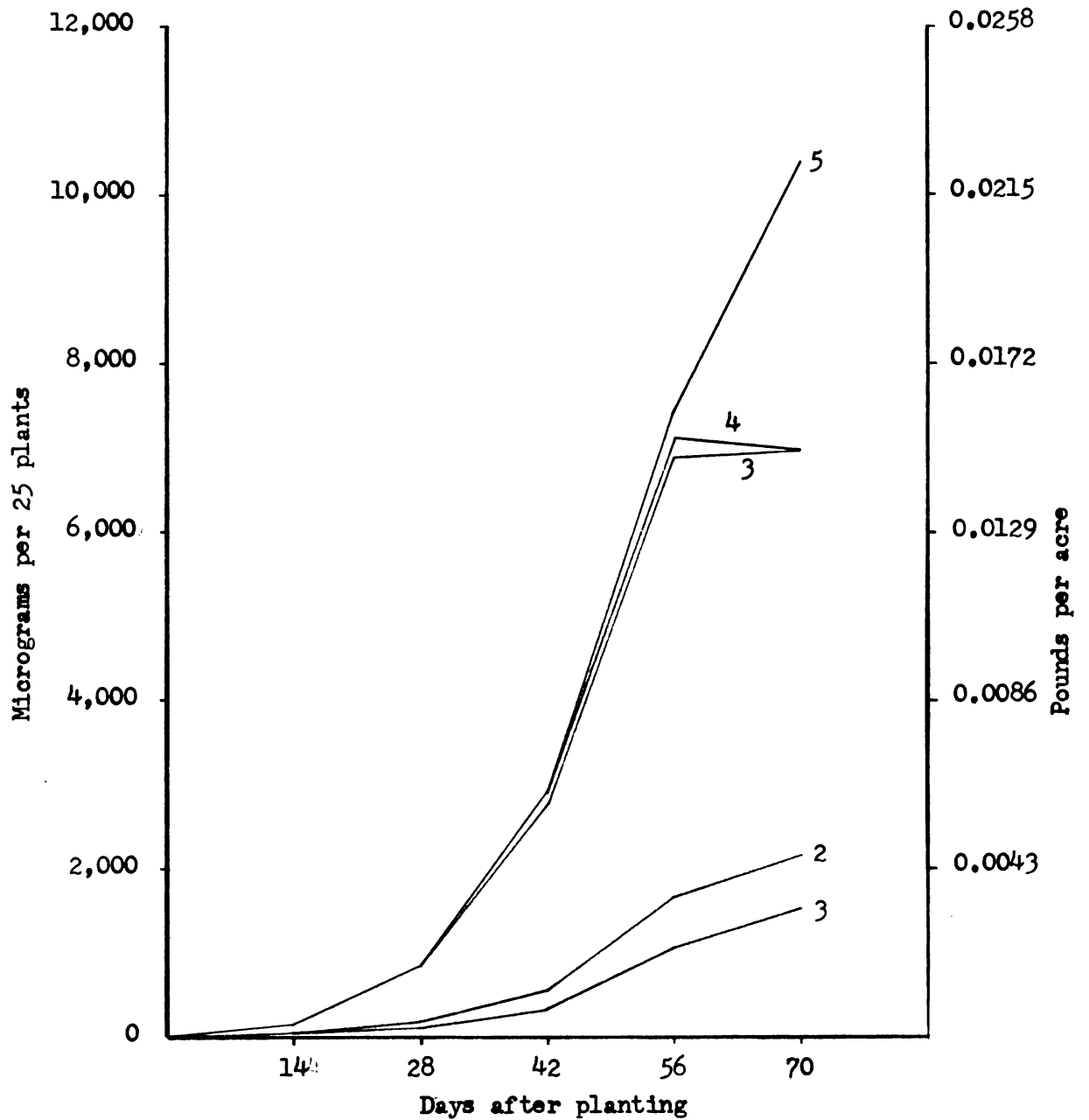
The pattern of total copper uptake of both varieties was similar, but the total copper uptake of the red kidney bean was slightly greater than in the white pea bean. The uptake on an acre basis was greater with the white bean primarily because this variety had a higher population.

Iron Content and Uptake of Bean Plants

The iron content of red kidney bean plants at six stages of growth is shown in Appendix XXI.

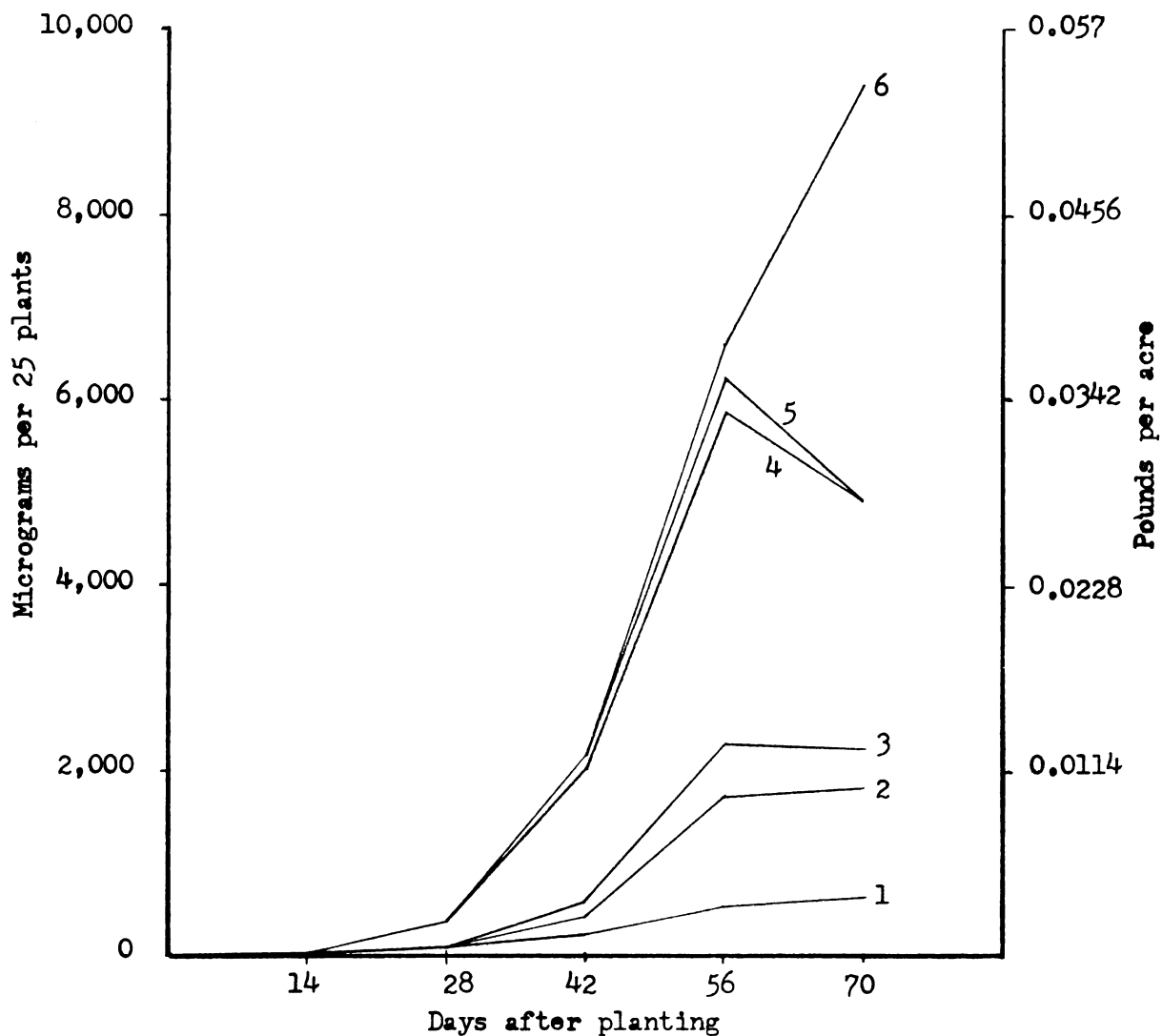
The iron concentration varied greatly from 41.5 ppm to 1000 ppm. The iron content of the leaf blade was higher than the petiole; also the iron concentration in most parts of the bean plant was relatively high during pod formation.

Figure 15. The copper uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 16. The copper uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

The iron concentration in the leaf blade and in the stem varied greatly during the growing season.

Similar data on the white pea bean are shown in Appendix XXII.

The iron content of the white bean plant ranged from 58.3 ppm to 1917 ppm, depending upon plant part and the stage of growth. The iron content of the leaf blade was higher than the petiole. The concentration in the leaf blades and the stems varied greatly during the growing season. The iron content of the branches tended to increase as the plant approached the mature stage.

The iron concentration in the white bean was generally higher than in the red kidney bean. In both varieties there was less iron in the seed than in the shell.

The uptake of iron by the red kidney bean plant is shown in Figure 17. As with other elements, the uptake varied greatly with age and part of the plant.

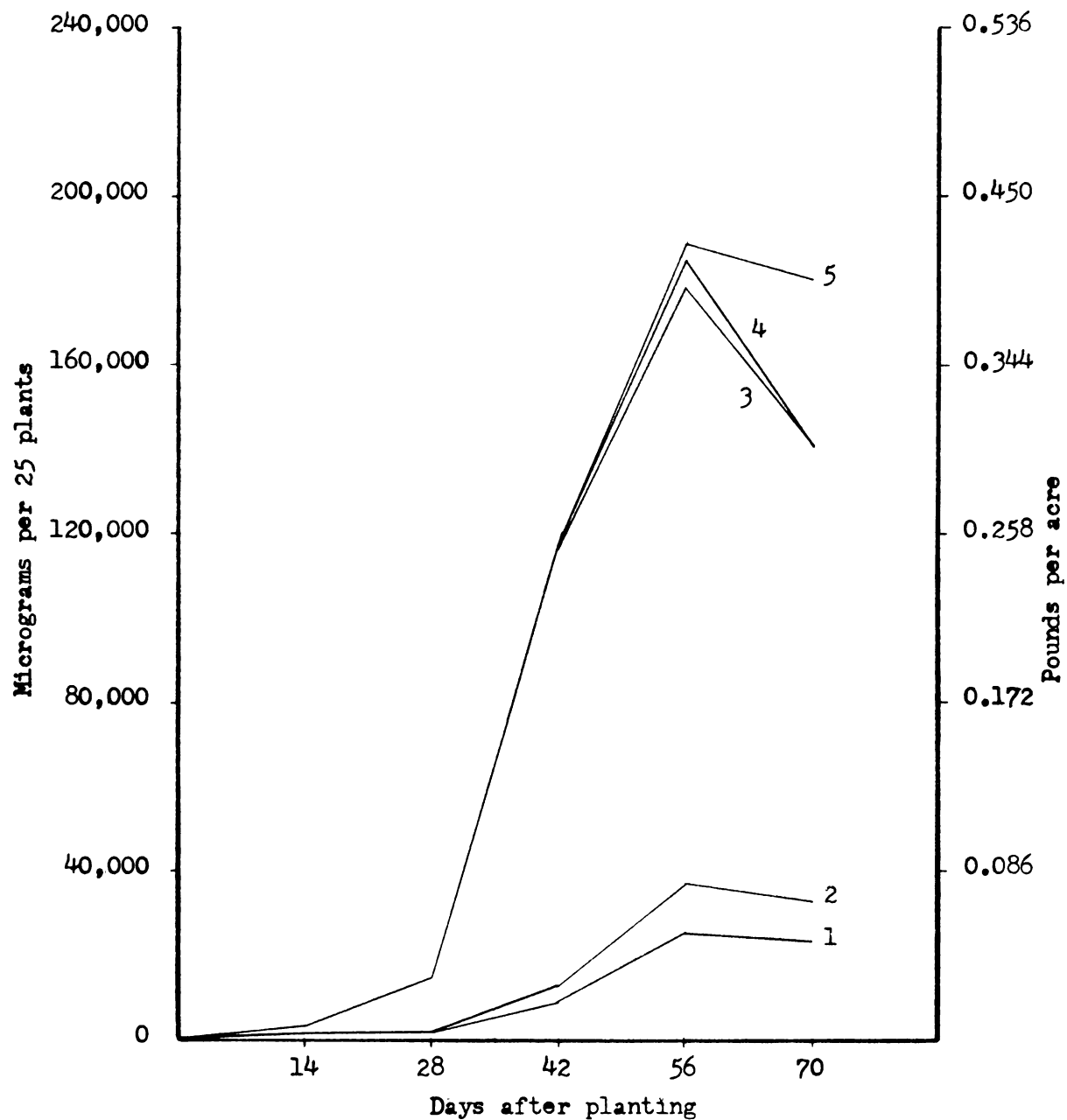
The rate of uptake increased rapidly after 28 days. The accumulation of iron in the leaf blade was much greater than in any other part of the plant. The uptake by the pods, flowers, petioles, and stems was very small in comparison with the leaf blade.

The apparent loss of iron during the last sampling period is attributed to a loss of leaves between samplings.

The curves describing the uptake of iron by the white pea bean are similar to those already described (Figure 18).

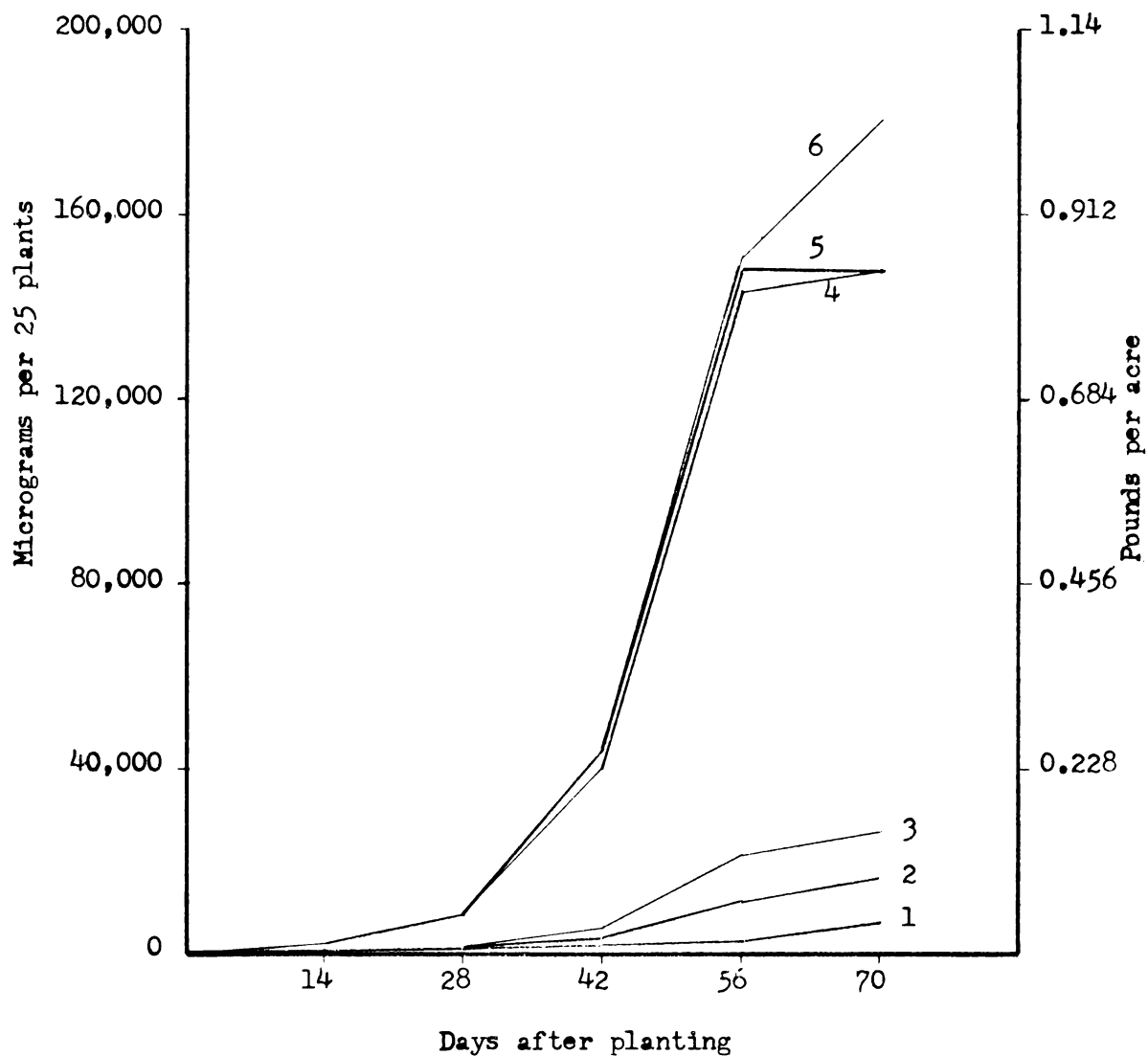
The period of rapid accumulation in the leaves, however, occurred two weeks later in the season. This primarily

Figure 17. The iron uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 18. The iron uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

reflected an earlier rapid growth and period of leaf formation in the red kidney beans.

Manganese Content and Uptake of Bean Plants

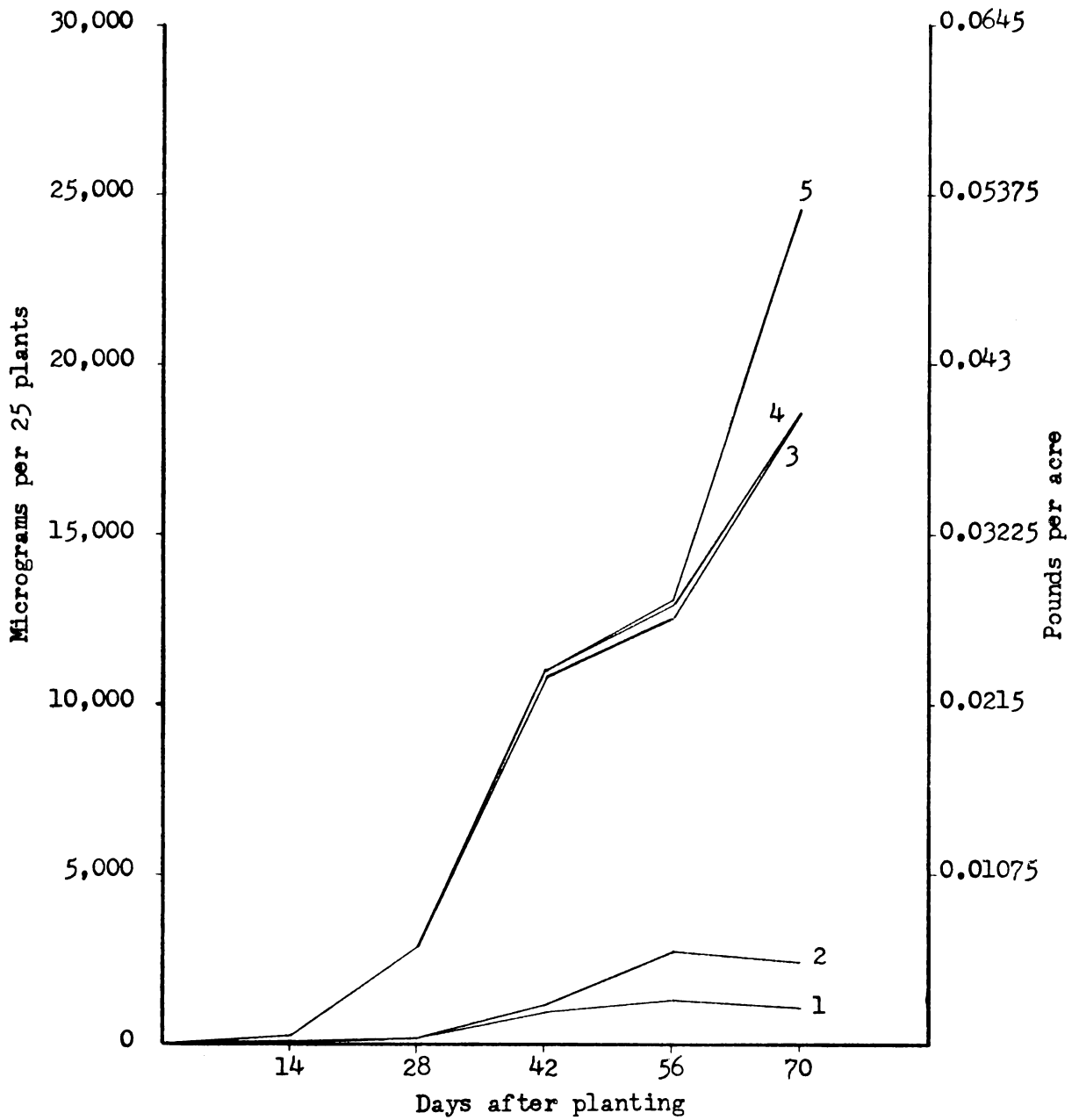
The manganese content of the red kidney bean is shown in Appendix XXIII. The content varied between 2.8 and 91.5 ppm, depending upon the two variables--age and plant part. The manganese in the leaf blade was always higher than in the petiole. The manganese tended to reach higher levels of concentration during the flower and pod formation period. The shell of the mature pods contained more than five times that measured in the seed.

Similar data for the white pea bean are located in Appendix XXIV. The manganese content was slightly higher than in the red kidney bean. The content ranged between 5.6 and 10.8 ppm.

With one exception, the manganese content of two varieties of beans showed a very similar distribution. In mature pods of the red kidney bean the manganese content was much higher in the shell than in the seed. In the white pea bean, this was not the situation in that the two parts contained similar concentrations, 16.6 ppm in the shell and 20.7 ppm in the seed.

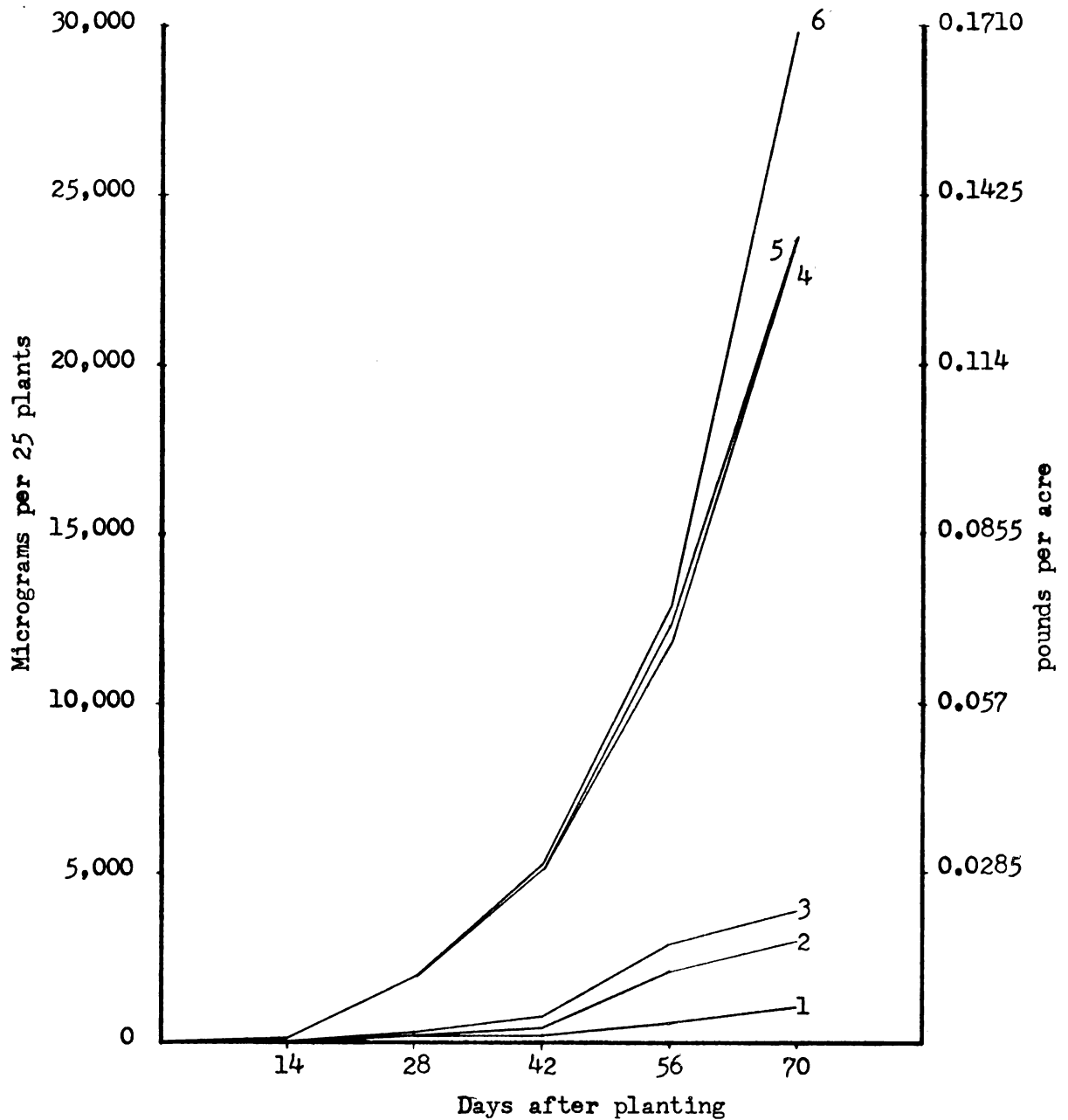
The uptake of manganese is shown in Figures 19 and 20. The leaf blades of the two varieties contained the most manganese. In both varieties, after 14 days, the uptake rate increased significantly and even more after 28 days.

Figure 19. The manganese uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 20. The manganese uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

Zinc Content and Uptake of Bean Plants

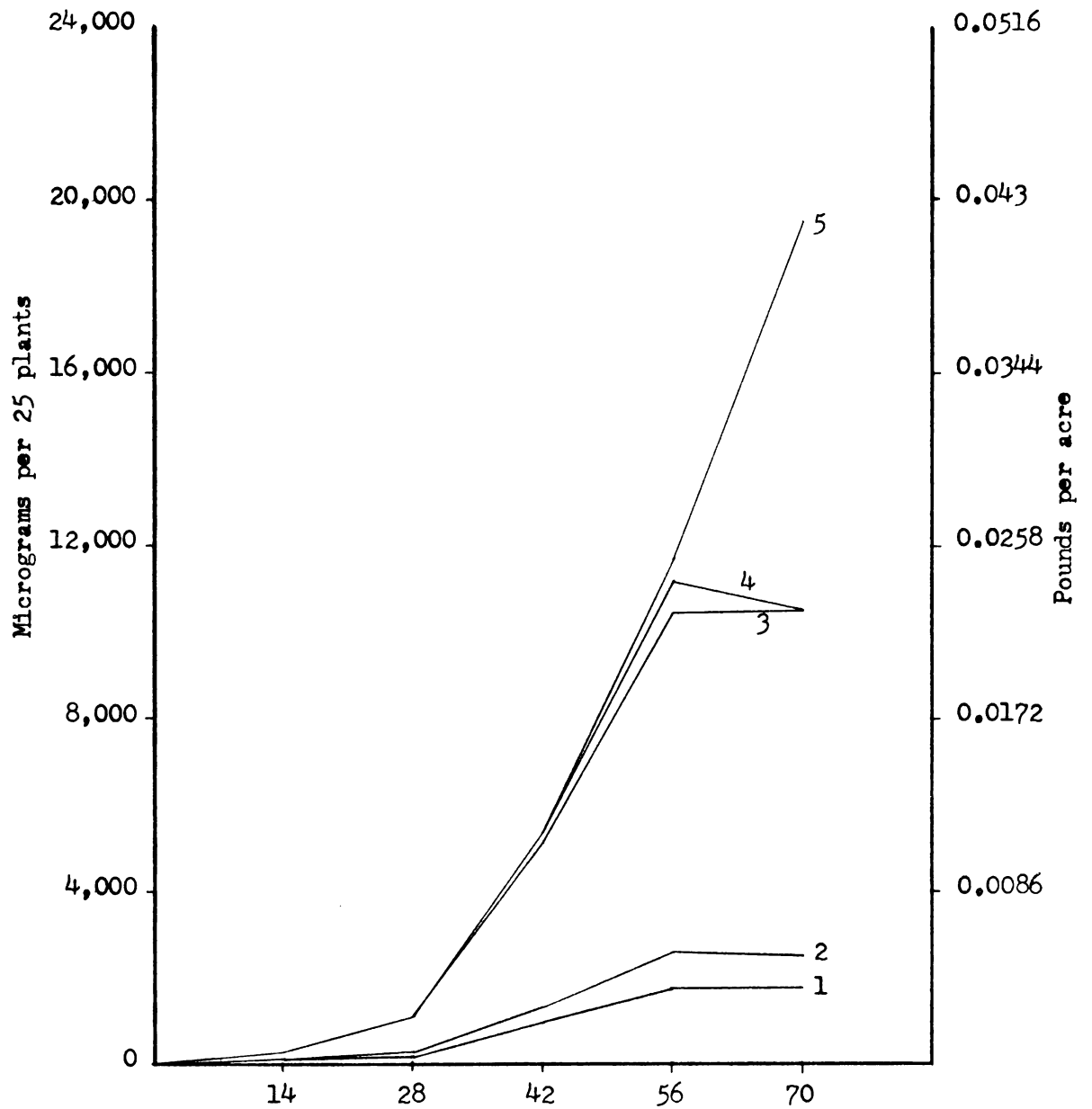
The zinc content of red kidney beans is shown in Appendix XXV. The concentration varied between 8.0 and 56.0 ppm. During the growing season the zinc content of the stem varied between 12.7 and 27.6 ppm with no evidence of an upward or downward trend being present.

The petioles of the leaves ranged between eight and 29 ppm while the blade ranged between ten and 50 ppm. Again the content did not seem to be closely related to age of the plant except there was a small indication that the under-sized immature leaves might contain a higher level of zinc.

Similar results were obtained with the white pea bean (Appendix XXVI). In both varieties, the zinc content of the seed was approximately double that of the shell.

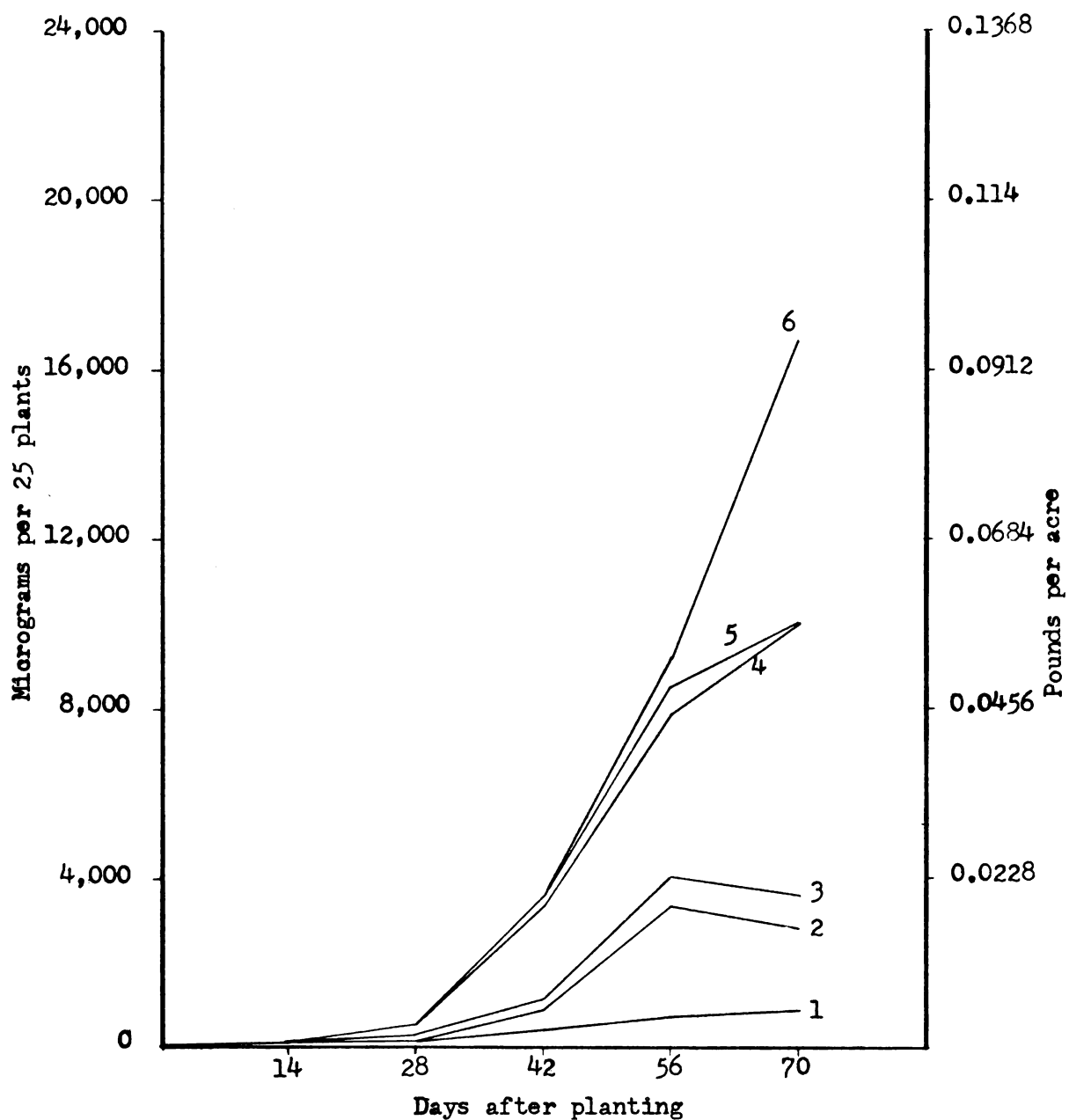
The uptake of zinc is shown in Figures 21 and 22. As with iron, the uptake increased rapidly after 28 days and in both varieties was present in the greatest amount in the leaves. The pods also contained significant quantities.

Figure 21. The zinc uptake by the red kidney bean plant.



- 1 : Stem.
- 2 : Stem + petiole.
- 3 : Stem + petiole + leaf blade.
- 4 : Stem + petiole + leaf blade + flower.
- 5 : Stem + petiole + leaf blade + flower + pod.

Figure 22. The zinc uptake by the white pea bean plant.



- 1 : Stem.
- 2 : Stem + branch.
- 3 : Stem + branch + petiole.
- 4 : Stem + branch + petiole + leaf blade.
- 5 : Stem + branch + petiole + leaf blade + flower.
- 6 : Stem + branch + petiole + leaf blade + flower + pod.

V. DISCUSSION

This research project was initiated for several reasons, some of which are not obvious to the casual observer. Being from another country, the author was not as experienced in many areas of soil science research methods, research planning, and in crop production methods.

While collecting field data for this thesis project, the author was able to see and study the ever-changing scene in the countryside between East Lansing and Saginaw. Much space could be devoted to the observations made on rural people, and the apparent conflict between the use of soil for crop and livestock production, and the use of land by the automobile industry.

While collecting samples for analysis, the author met and became acquainted with representatives of several businesses, including the Cooperative Extension Service, the fertilizer industry and some farmers. With a laboratory or greenhouse project, the author would not have had such opportunities.

In working outside, the author also was able to see other field research in progress, such as the other plots on the Johnson farm, the research on field beans sponsored by organizations not directly connected with Michigan State University, and the research on the Lee Ferden farm sponsored in part by The Farmers and Manufacturers Beet Sugar Association.

Some might say that these few paragraphs do not belong in a thesis. But without these experiences, it would be difficult to understand and appreciate why this particular research project is important or how the research could best be done, and the results used.

Without such a background, would it be possible to know well what kind of a research project is really important? Without such experiences, would it be possible to know where and who might expedite the details involved in research procedures?

The nutrition of beans is not necessarily a new subject. In the past, considerable work has been done in both greenhouse and in the field.

Perhaps, some of the first work of this nature was done in an attempt to diagnose plant nutrient deficiency symptoms. The leaves, the stems, or the entire plant were analysed for single elements. At a later date, it was learned that there might be interactions involved between certain essential plant food elements.

In the literature, there is considerable information on the chemical composition of certain parts of the bean plant, but there is little information on total uptake and the chemical composition of the several component parts.

This project was therefore outlined taking into consideration not only the need for information but also possible sources of funds and time available to a foreign student to complete the project.

The work discussed in Part I was designed to carry on

for another year the research already in progress. Already three years yield data have been collected from these plots. The zinc content of small immature plants has been determined. To grow beans the fourth year would be desirable if it could be done economically. Therefore, only one replication from the original experiment was used. The other replications were planted to several kinds of field crops and vegetables. No reference to the other crop is made in this thesis.

The visual growth characteristic as well as the seed yield produced in 1968, in general, were similar to those produced in previous years. The dry matter accumulations are, therefore, considered to be representative of the treatments and the soil in which the beans were grown.

As previously suspected, the Charlevoix variety of red kidney bean responded less to the use of zinc fertilizers than did the Sanilac variety of white pea beans.

The question "why" now should be answered as this study established the fact that on this soil there was a difference in the two varieties in their abilities to grow under conditions of a medium to low level of zinc.

The use of zinc on a zinc deficient soil in the production of field beans increased the number of leaves per plant, the number of pods per plant, the number of seeds per pod, and the general size of the plant. Naturally all of this was reflected in an increased seed yield. One other important observation was made. The use of zinc on a zinc deficient soil significantly and materially hastened the maturity

of both varieties of bean.

Again the question "why" or "how" should be asked because the specific functions of zinc are not now well understood. These observations should serve as a basis for future research--perhaps some of it may be done by students from other countries, such as Thailand.

The fact that a response was detected in the growth of bean plants only 14 days after planting suggests that zinc should be used as a planting or even as a preplanting treatment. Theoretically, zinc applied as a side dressing or as a foliar spray would result in less than maximum yield due to the possibility of a deficiency developing prior to such time of application,

In the section labeled Part II of the project, one of the highest yielding plots was used as a source of plant material for chemical analysis. The work had been planned and the plots managed with the best known methods and equipment. The only uncontrolled factor was the weather.

All of the analytical data are shown in the Appendix so that it will be available when more work of this nature is done. It is unfortunate that only one year's data could be included in this project. The results would be more significant and useable if two or even three years' results were available, or if results from other locations could be utilized. This, however, was not possible under the time restrictions encountered by the author.

The most practical use of these data is to consider

the results in the light of what happened at one location in one year. If this is done, then, it would be recognized that under other circumstances, there logically might be some deviation from these data.

The data representing the Charlevoix red kidney bean variety should be used with care until more information on this variety is available. The seed yields of this variety were disappointingly low. The reasons for the yield on this plot being only fourteen bushels per acre is not fully understood. It is not possible to look backward at this time and explain this yield level because most of the conditions affecting yield were considered to be regulated at a high level. Because of this situation, the following comments are restricted to the Sanilac white pea bean.

The white pea bean at maturity contained approximately 155 pounds per acre of nitrogen. Most of the nitrogen is thought to have been obtained from the supply fixed in nodules on the roots although some undoubtedly was derived from the planting time fertilizer and from the decomposition of the organic matter in the soil. The maximum amount and uptake occurred in the two-week period prior to maturity, between 56 and 70 days.

Approximately 13 pounds per acre of phosphorus was found in the white pea bean plants at maturity. As with nitrogen, most of the phosphorus was taken up during the last two week period and was concentrated in the pod. As

the seed matured much of the nitrogen and phosphorus was translocated into the seed.

Approximately 50 percent of the 85 pounds per acre of potassium was absorbed by the plant during the last two weeks and was concentrated in the pod. In contrast with nitrogen and phosphorus, most of the potassium remained in the shell of the pod. The uptake of 85 pounds per acre of potassium was somewhat less than expected.

Curiously the calcium content of this crop exceeded the potassium content by about 30 pounds per acre. This also was not expected. The explanation for this situation is possibly related to the fact that the beans were grown on a high pH soil. The high level of calcium in the plant may have restricted the uptake of potassium. This possibility should be investigated if in the future it is determined that there is an inadequate amount of potassium.

The uptake of calcium during the growing season was relatively constant. Very little change in uptake rate was detected after six weeks. In contrast with those elements already considered, the calcium was present in largest quantities in the leaves, particularly the blade.

This was also the situation with magnesium. In fact the calcium and magnesium curves are very similar except that the magnesium levels were only about ten percent as high as the calcium. After four weeks the uptake rate of calcium reached the maximum and remained relatively

constant during the rest of the season.

The white pea bean crop contained less than 0.06 pounds of copper, 1.00 pounds of iron, 0.17 pounds of manganese, and 0.10 pounds of zinc. In each instance, these elements were concentrated in the leaves with relatively small amounts accumulating in the pods. The maximum uptake rate of copper occurred between the six and eight week sampling periods, the period of heaviest bloom.

The most rapid accumulation of iron occurred at the same time with the higher proportion of the iron accumulating in the leaves.

The accumulation of manganese was relatively constant, being most rapid in the last two week period. This probably explains in part why spraying manganese onto the leaves has been considered to be an effective method for using this micronutrient.

The uptake curves for zinc and manganese are similar. They differ in that the rapid uptake of zinc did not start until two weeks later in the growing season.

In interpreting these data, it is safe to assume that the accumulation of the nutrients considered in this project was such that neither deficiencies nor toxicities occurred. The quantities of 155 pounds of nitrogen, 13 pounds of phosphorus, 85 pounds of potassium, 115 pounds of calcium, 30 pounds of magnesium, 0.06 pounds of copper, 1.00 pounds of iron, 0.17 pounds of manganese, and 0.10 pounds of zinc was

sufficient to produce a 38.6 bushel crop. It may have been sufficient to produce an even higher yield had the weather or the variety been different.

VI. SUMMARY AND CONCLUSIONS

Two varieties of beans, a red kidney and white pea bean, were grown in the field. Each variety was fertilized with two rates of two zinc-containing materials. The experiment contained two "no zinc" plots.

The use of zinc on a zinc deficient soil greatly increased the yield of the seed in both varieties of beans. The increase in yield was caused by an increase in the number of pods per plant, number of seeds per pod and an increase in number of leaves per plant.

Zinc fertilizers also hastened the maturity of both varieties. The effect of added zinc could be detected fourteen days after planting by measuring the accumulation of dry matter in the small plants.

Broadcast application of relatively high rates of both zinc carriers (more than 25 pounds of zinc per acre) produced more dry matter per plant than low rates banded at planting time.

One plot, which historically had produced as well as, or better than, other plots, was used as a source of plant material for chemical evaluation of nutrient uptake. Samples were collected every two weeks during the growing season. The plants were subdivided into their component parts--stems, petioles of leaves, blades of leaves, flowers and pods. At harvest time the pods were divided into "seed" and

"shell" fractions.

The several parts of the plant were chemically analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, copper, iron, manganese and zinc. Depending upon the part of the plant considered, the nutrient content varied greatly. Nutrient uptake data are presented in graphic form.

The nitrogen content of the stem in both varieties of beans decreased with time. The concentration of nitrogen in the leaf blade was always higher than in the petiole. Small and young seed pods contained more than four percent nitrogen. As the seed developed the nitrogen content of the pod decreased as the nitrogen moved into the seed.

As with nitrogen, the concentration of phosphorus decreased with the age of the plant. In older plants, phosphorus was concentrated in the leaf blade and in the pod. The blade contained a higher concentration of phosphorus than the petiole. The total uptake of phosphorus was only six pounds per acre in the red kidney bean and thirteen pounds per acre in the white pea bean.

The percent potassium varied from a low 0.30 percent in the blade of the older leaves of the red kidney beans to 6.5 percent in the petiole of the first formed true leaf. The concentration of potassium in both varieties was higher in the petiole than in the leaf blade. The concentration in most parts of the plant was greatest during the flowering stage. The uptake of potassium increased rapidly after

two weeks, and reached a maximum as the plants approached maturity.

The uptake rate of calcium increased with time and accumulated in largest quantities in the leaf blade.

The magnesium levels were only one-third as high as calcium and were concentrated in the leaf blade.

The bean crops contained less than 0.06 pounds per acre of copper, 1.00 pounds of iron, 0.17 pounds of manganese and 0.10 pounds of zinc. In each instance these elements were concentrated in the leaves with relatively small amounts in the pods.

In conclusion, before the data presented here can be used extensively, the same kind of research should be done in other years and on other soils. Basic work on nutrient uptake and possible interactions between the several nutrients would be desirable.

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LITERATURE CITED

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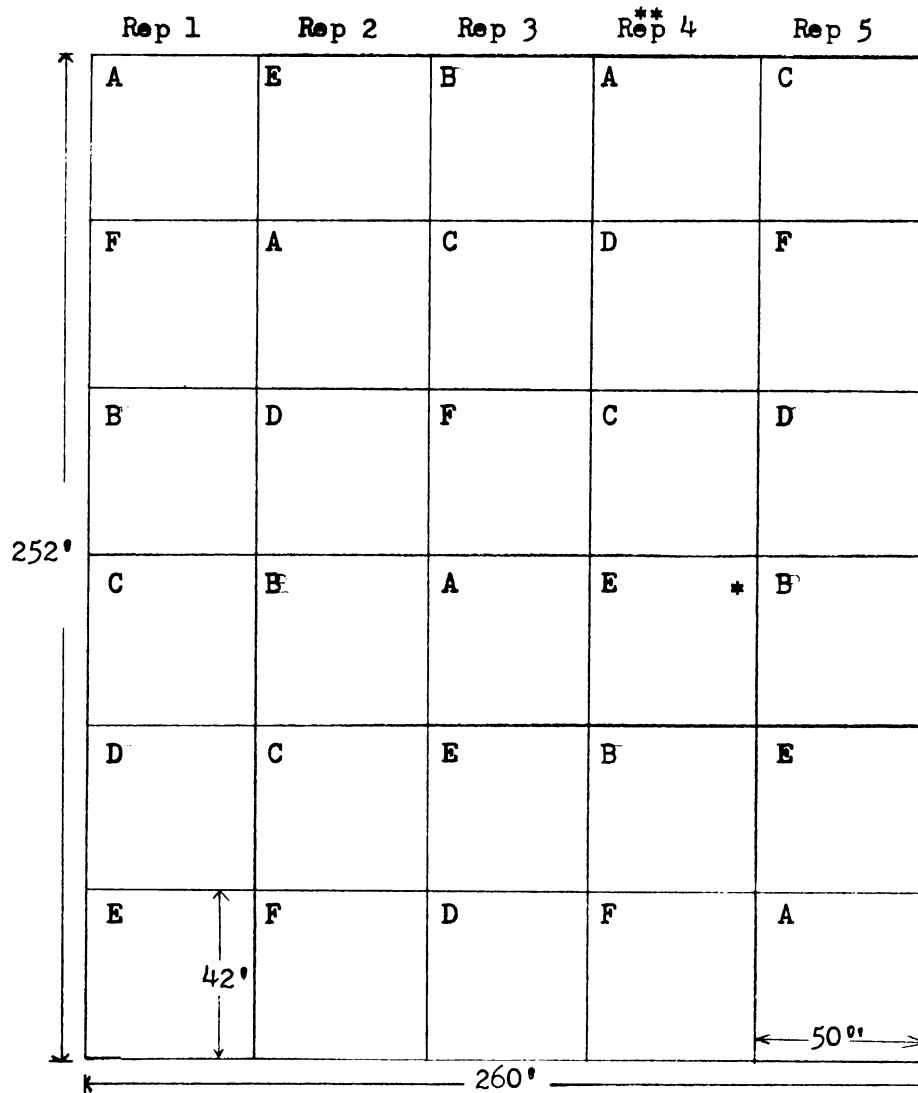
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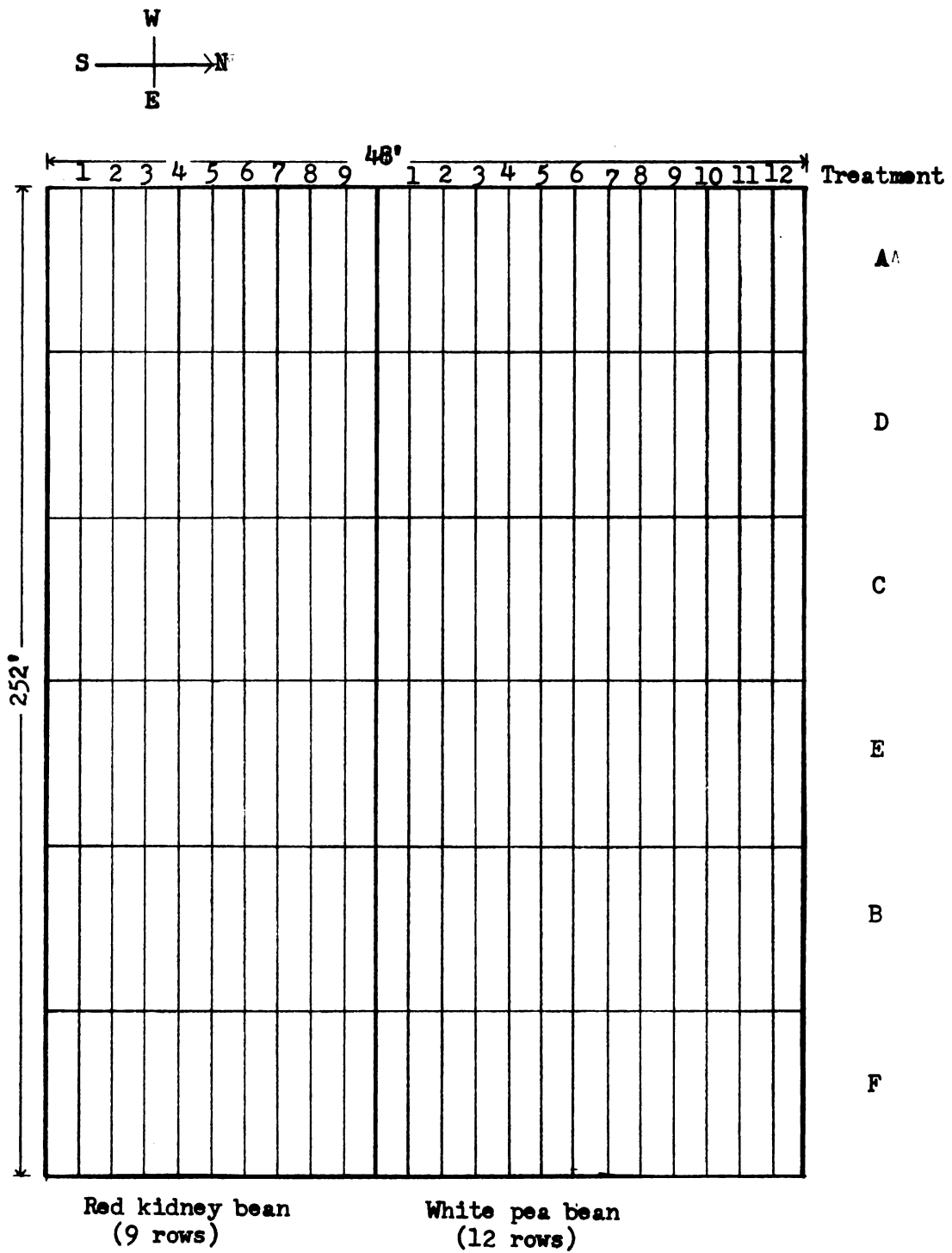
APPENDIX

Appendix I. The original plot outline describing treatments made in 1965 and location of the plot area studied in 1968.



- A : No zinc.
 B : 3.0 pounds per acre zinc as banded zinc sulfate.
 C : 73.5 pounds per acre zinc as a broadcasted zinc residue material.
 D : 122.5 pounds per acre zinc as a broadcasted zinc residue material.
 E : 25 pounds per acre zinc as broadcasted zinc sulfate.
 F : No zinc.
 * Location of sample area for chemical analysis.
 ** Location of sample area for dry weight.

Appendix II. Field diagram of 1968 plots showing of where the two varieties of beans were grown.



APPENDIX III. THE GRAM DRY WEIGHT OF 10 RED KIDNEY BEAN
PLANTS AS AFFECTED BY TIME AND ZINC CON-
TAINING FERTILIZER

Sampling Time	Days After Plant- ing	Treatment*					
		A	B	C	D	E	F
1	14	4.86	4.90	5.20	4.82	5.02	4.76
2	28	18.82	23.42	23.38	22.40	26.44	19.88
3	42	50.57	77.60	91.46	71.08	93.04	36.20
4	56	120.83	153.75	138.18	148.45	161.55	98.00
5	70	255.22	254.82	244.87	358.45	300.73	61.85
6	84	278.90	269.30	277.95	311.25	352.80	109.90
7	98	207.70	208.60	255.70	269.20	289.60	118.05

*A = No Zinc

B = 3 pounds per acre zinc as banded zinc sulfate

C = 73.5 pounds per acre zinc as a broadcasted zinc
residue material

D = 122.5 pounds per acre zinc as a broadcasted zinc
residue material

E = 25 pounds per acre zinc as broadcasted zinc sulfate

F = No zinc

APPENDIX IV. THE GRAM DRY WEIGHT OF 10 WHITE PEA BEAN
PLANTS AS AFFECTED BY TIME AND ZINC CON-
TAINING FERTILIZER

Sampling Time	Days After Plant- ing	Treatment*					
		A	B	C	D	E	F
1	14	1.50	1.97	1.71	1.71	2.10	1.61
2	28	6.42	13.50	15.08	11.55	13.75	5.08
3	42	13.66	53.58	74.08	75.43	64.30	8.82
4	56	34.55	108.85	96.83	161.80	126.66	11.04
5	70	71.50	167.30	236.80	353.95	279.97	7.02
6	84	74.95	192.30	281.25	265.45	353.65	15.45
7	98	73.95	203.05	288.38	216.15	215.50	16.38

* A = No zinc

B = 3.0 pounds per acre zinc as banded zinc sulfate

C = 73.5 pounds per acre zinc as a broadcasted zinc
residue material

D = 122.5 pounds per acre zinc as a broadcasted zinc
residue material

E = 25.0 pounds per acre zinc as broadcasted zinc
sulfate

F = No zinc

APPENDIX V SUMMARY OF DRY WEIGHTS OF VARIOUS PART OF
25 RED KIDNEY BEAN PLANTS AT SIX STAGES
OF GROWTH

Plant Part	Days after Planting					
	14	28	42	56	70	84
Root Stub	1.33	6.46	18.87	40.75	56.2	54.22
Stem	2.15	10.26	45.69	102.00	128.85	125.40
Petiole	0.61	3.92	16.85	36.21	36.45	10.15
Leaf Blade	7.09	45.14	141.87	222.05	242.4	56.40
Flower			11.11	11.78		
Pod				12.87	297.95	607.63

APPENDIX VI THE GRAM WEIGHTS OF THE COMPONENT PARTS OF 25
RED KIDNEY BEAN PLANTS AT SIX STAGES OF PLANT
GROWTH

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem (including branches)	2.15	10.26	45.69	102.00	128.85	125.40
Cotyledon	1.48	--	--	--	--	--
Petiole of primary leaf	0.61	1.03	1.15			
Leaf blade of primary "	7.09	17.09	15.62			
Petiole of first true leaf		1.13				
Leaf blade of the first true leaf		14.78				
Petiole of the 2nd true leaf		0.86				
Leaf blade of the 2nd true leaf		8.66				
Petiole of the 3rd true leaf		0.90				
Leaf blade of the 3rd true "		4.61				
Miscellaneous		6.08	11.11	11.78		
Petiole of older leaf				7.08	18.33	10.15
Leaf blade of older leaf				50.25	117.74	56.40
Petiole of large leaf			15.70	23.48	13.92	
Leaf blade of large leaf			126.25	140.35	100.93	
Petiole of small leaf				5.65	4.20	
Leaf blade of small leaf				31.45	23.73	
Immature pod				12.87	153.08	
Shell of immature pod					159.55	123.45
Seed of immature pod					85.32	211.60
Shell of mature pod						83.10
Seed of mature pod						189.48

APPENDIX VII SUMMARY OF DRY WEIGHTS OF VARIOUS PARTS OF 25
WHITE PEA BEAN PLANTS AT SIX STAGES OF GROWTH

Plant Part	Days after planting					
	14	28	42	56	70	84
Root-Stub	0.51	3.38	9.99	20.70	28.60	27.9
Stem	0.71	5.16	22.24	41.85	46.90	38.20
Petiole	0.26	4.45	16.16	39.06	41.30	2.65
Leaf Blade	2.45	22.10	95.80	170.33	323.32	21.98
Flower			5.27	13.45		
Branch			13.52	71.92	138.15	90.37
Pod				18.85	349.82	565.40

APPENDIX VIII THE GRAM WEIGHTS OF THE COMPONENT PARTS OF
25 WHITE PEA BEAN PLANTS AT SIX STAGES OF
PLANT GROWTH

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	0.71	10.26	22.24	41.85	46.90	38.20
Cotyledon	0.41					
Petiole of primary leaf	0.26	0.99	0.94			
Leaf blade of primary leaf	2.45	5.25				
Petiole of 1st true leaf		1.25				
Leaf blade of 1st true "		7.35				
Petiole of 2nd true leaf		1.19	9.36	18.80	15.90	
Leaf blade of 2nd true leaf		6.07	54.28	100.50	85.50	
Petiole of 3rd true leaf		1.02				
Leaf blade of 3rd true leaf		3.43				
Miscellaneous		4.86	5.27	13.45		
Petiole of older leaf			3.34	9.81	19.90	2.65
Leaf blade of older leaf			22.57	18.70	105.00	21.98
Petiole of small leaf			3.46	10.45	5.50	
Leaf blade of small leaf			18.95	51.13	132.82	
1st branch			4.77	18.60	40.10	25.70
2nd branch			3.16	12.77	24.75	18.20
3rd branch			2.74	11.55	20.02	14.00
4th branch			1.71	8.30	17.58	14.45
5th branch			0.73	6.25	15.82	7.00
6th branch			0.30	6.55	11.28	4.40
7th branch			0.11	4.47	7.85	4.80
8th branch				2.28	0.75	1.82
9th branch				1.15		
Immature pod				18.85	188.5	
Shell of immature pod					86.25	47.40
Seed of immature pod					75.05	85.15
Shell of mature pod						110.55
Seed of mature pod						322.30

APPENDIX IX THE NITROGEN CONTENT OF THE VARIOUS PARTS OF
THE RED KIDNEY BEAN AT SIX STAGES OF GROWTH
(PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	4.80	2.41	1.94	1.84	1.75	1.18
Cotyledon	2.20	-	-	-	-	-
Petiole of primary leaf	4.66	1.96	1.32			
Leaf blade of primary leaf	6.07	3.88	2.39			
Petiole of 1st true leaf		2.28				
Leaf blade of 1st true leaf		5.45				
Petiole of 2nd true leaf		2.31				
Leaf blade of 2nd true leaf		5.33				
Petiole of 3rd true leaf		2.91				
Leaf blade of 3rd true leaf		5.07				
Miscellaneous		4.44	1.99	2.35		
Petiole of older leaf				1.51	0.52	1.33
Leaf blade of older leaf				2.76	2.92	2.73
Petiole of large leaf			1.79	1.50	1.40	
Leaf blade of large leaf			4.41	3.97	3.78	
Petiole of small leaf				1.88	2.01	
Leaf blade of small leaf				4.91	0.74	
Immature pod				4.35	1.15	
Shell of immature pod					2.66	0.85
Seed of immature pod					4.28	4.00
Shell of mature pod						1.07
Seed of mature pod						4.11

APPENDIX X THE NITROGEN CONTENT OF THE VARIOUS PARTS OF
THE WHITE PEA BEAN PLANTS AT SIX STAGES OF
GROWTH (PERCENT)

Plant Part	Days After Planting					
	14	28	42	56	70	84
Stem	3.80	1.85	1.42	1.27	1.14	1.15
Cotyledon	1.02	-	-	-	-	-
Petiole of primary leaf	-	1.08	3.15			
Leaf blade of primary leaf	5.61	3.15				
Petiole of 1st true leaf		--				
Leaf blade of 1st true "		4.79				
Petiole of 2nd true leaf		1.88	1.53	1.19	1.42	
Leaf blade of 2nd true "		5.80	4.48	3.74	4.03	
Petiole of 3rd true leaf		--				
Leaf blade of 3rd true "		6.01				
Miscellaneous		5.72	2.76	4.82		
Petiole of older leaf			1.31	1.06	1.08	1.31
Leaf blade of older leaf			3.20	2.34	3.09	2.01
Petiole of small leaf			2.92	1.66	1.71	
Leaf blade of small leaf			5.29	4.33	4.22	
1st branch			2.01	2.34	1.70	1.18
2nd branch			3.91	1.61	1.68	1.86
3rd branch			2.34	1.46	1.65	1.18
4th branch			2.39	1.71	1.61	0.91
5th branch			2.34	2.05	1.63	1.18
6th branch			--	1.94	1.47	0.96
7th branch				1.93	1.64	0.77
8th branch				1.68	--	1.24
9th branch				2.04	--	
Immature pod				4.29	2.90	
Shell of immature pod					1.65	1.53
Seed of immature pod					4.38	4.06
Shell of mature pod						1.42
Seed of mature pod						4.11

APPENDIX XI THE PHOSPHORUS CONTENT OF THE VARIOUS PARTS OF
THE RED KIDNEY BEAN PLANTS AT SIX STAGES OF
GROWTH (PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	0.55	0.34	0.26	0.16	0.29	0.07
Cotyledon	0.23	-	-	-	-	-
Petiole of primary leaf	0.68	0.30	0.14			
Leaf blade of primary "	0.59	0.27	0.20			
Petiole of 1st true leaf		0.41				
Leaf blade of 1st true "		0.41				
Petiole of 2nd true leaf		0.25				
Leaf blade of 2nd true "		0.48				
Petiole of 3rd true leaf		0.16				
Leaf blade of 2nd true "		0.57				
Miscellaneous		0.70	0.19	0.57		
Petiole of older leaf				0.14	0.13	0.09
Leaf blade of older leaf				0.19	0.14	0.15
Petiole of large leaf			0.32	0.16	0.10	
Leaf blade of large leaf			0.30	0.22	0.20	
Petiole of small leaf				0.20	0.10	
Leaf blade of small leaf				0.34	0.27	
Immature pod				0.57	0.40	
Shell of immature pod					0.10	0.09
Seed of immature pod					0.60	0.36
Shell of mature pod						0.06
Seed of mature pod						0.36

APPENDIX XII THE PHOSPHORUS CONTENT OF THE VARIOUS PARTS
OF THE WHITE PEA BEAN PLANTS AFTER SIX STAGES
OF GROWTH (PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	0.45	0.31	0.23	0.16	0.18	0.05
Cotyledon	0.17	--	--	--	--	--
Petiole of primary leaf	0.76	0.24	0.19	--	--	--
Leaf blade of primary "	0.53	0.23				
Petiole of 1st true leaf		0.38				
Leaf blade of 1st true "		0.34				
Petiole of 2nd true leaf		0.55	0.23	0.15	0.12	
Leaf blade of 2nd true "		0.41	0.35	0.20	0.21	
Petiole of 3rd true leaf		0.41				
Leaf blade of 3rd true "		0.61				
Miscellaneous		0.83	0.73	0.59		
Petiole of older leaf			0.20	0.12	0.15	0.12
Leaf blade of older leaf			0.25	0.15	0.20	0.22
Petiole of small leaf			0.36	0.22	0.17	
Leaf blade of small leaf			0.55	0.31	0.22	
1st branch			0.29	0.15	0.20	0.10
2nd branch			0.31	0.24	0.19	0.09
3rd branch			0.30	0.20	0.18	0.07
4th branch			0.30	0.24	0.17	0.08
5th branch			0.30	0.21	0.18	0.06
6th branch			0.30	0.26	0.19	0.05
7th branch				0.24	0.17	0.04
8th branch				0.19	}	0.04
9th branch				0.25		
Immature pod				0.52	0.29	
Shell of immature pod					0.15	0.20
Seed of immature pod					0.55	0.55
Shell of mature pod						0.04
Seed of mature pod						0.46

APPENDIX XIII THE POTASSIUM CONTENT OF THE VARIOUS PARTS
OF THE RED KIDNEY BEAN PLANT AT SIX STAGES
OF GROWTH (PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	3.82	3.75	2.97	1.42	1.35	0.92
Cotyledon	0.65	--	--	--	--	--
Petiole of primary leaf	2.00	5.0	3.75			
Leaf blade of primary "	2.87	3.45	1.22			
Petiole of 1st true leaf		6.50				
Leaf blade of 1st true "		3.57				
Petiole of 2nd true leaf		4.27				
Leaf blade of 2nd true "		3.52				
Petiole of 3rd true leaf		2.27				
Leaf blade of 3rd true "		3.32				
Miscellaneous		4.00	2.10	3.00		
Petiole of older leaf				2.45	1.45	2.07
Leaf blade of older leaf				0.90	0.30	0.32
Petiole of large leaf			3.75	1.85	2.45	
Leaf blade of large leaf			1.75	1.17	0.67	
Petiole of small leaf				2.82	2.77	
Leaf blade of small leaf				1.95	1.17	
Immature pod				3.15	2.20	
Shell of immature pod					1.87	2.20
Seed of immature pod					1.90	1.67
Shell of mature pod						2.55
Seed of mature pod						1.32

APPENDIX XIV THE POTASSIUM CONTENT OF THE VARIOUS PARTS
OF THE WHITE PEA BEAN PLANTS AT SIX STAGES
OF GROWTH (PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	3.94	4.15	2.7	1.0	1.07	0.47
Cotyledon	0.40	--	--	--	--	--
Petiole of Primary leaf	4.25	5.50	1.45			
Leaf blade of primary "	2.87	3.02				
Petiole of 1st true leaf		3.00				
Leaf blade of 1st true"		2.70				
Petiole of 2nd true leaf		6.00	4.57	2.82	2.85	
Leaf blade of 2nd " "		3.12	1.85	1.12	1.32	
Petiole of 3rd true leaf		4.50				
Leaf blade of 3rd " "		3.05				
Miscellaneous		3.25	3.07	3.37		
Petiole of older leaf			4.25	4.25	2.40	4.60
Leaf blade of older "			1.57	2.20	0.75	0.97
Petiole of small leaf			4.50	3.25	3.22	
Leaf blade of small "			2.07	1.97	1.65	
1st branch			3.32	1.70	1.62	1.20
2nd branch			3.90	1.77	1.67	1.37
3rd branch			4.02	1.45	2.37	1.17
4th branch			4.12	1.60	0.85	1.15
5th branch			3.95	1.70	1.65	1.02
6th bramch			3.85	1.60	1.77	1.07
7th branch				1.70	1.65	1.07
8th branch				1.55		1.50
9th branch				2.00	--	
Immature pod				2.65	2.12	
Shell of immature pod					2.20	2.65
Seed of immature pod					1.65	1.40
Shell of mature pod						2.75
Seed of mature pod						0.72

APPENDIX XV THE CALCIUM CONTENT OF THE VARIOUS PARTS OF
THE RED KIDNEY BEAN PLANTS AT SIX STAGES OF
GROWTH (PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	0.86	1.41	1.16	1.29	1.46	1.48
Cotyledon	1.46	--	--	--	--	--
Petiole of primary leaf	0.98	2.64	2.00			
Leaf blade of primary "	1.58	4.34	5.34			
Petiole of 1st true leaf		1.41				
Leaf blade of 1st true "		2.56				
Petiole of 2nd true leaf		0.52				
Leaf blade of 2nd true "		1.95				
Petiole of 3rd true leaf		0.08				
Leaf blade of 3rd true "		1.31				
Miscellaneous		1.06	1.06	1.58		
Petiole of older leaf				3.28	2.91	2.84
Leaf blade of older leaf				3.69	5.43	5.33
Petiole of large leaf			2.50	2.17	2.38	
Leaf blade of large leaf			2.90	3.74	3.91	
Petiole of small leaf				1.93	0.21	
Leaf blade of small leaf				2.11	3.41	
Immature pod				1.29	1.22	
Shell of immature pod					1.08	1.23
Seed of immature pod					0.48	0.22
Shell of mature pod						1.06
Seed of mature pod						0.14

APPENDIX XVI THE CALCIUM CONTENT OF THE VARIOUS PARTS OF
THE WHITE PEA BEAN PLANTS AT SIX STAGES OF
GROWTH (PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	1.66	1.58	1.06	0.94	1.56	1.40
Cotyledon	2.47	-	-	-	-	-
Petiole of primary leaf	1.57	2.85	4.64			
Leaf blade of primary "	2.36	5.63				
Petiole of 1st true leaf		2.54				
Leaf blade of 1st true "		4.05				
Petiole of 2nd true leaf		1.81	1.70	2.28	2.40	
Leaf blade of 2nd true "		3.04	2.93	4.09	3.68	
Petiole of 3rd true leaf		1.14				
Leaf blade of 3rd true "		2.17				
Miscellaneous		1.41	1.00	1.61		
Petiole of older leaf			2.78	3.95	3.21	1.40
Leaf blade of small leaf			5.37	6.58	5.54	4.84
Petiole of small leaf			1.25	1.82	2.00	
Leaf blade of small leaf			1.90	2.88	2.63	
1st branch			1.14	0.94	1.46	1.73
2nd branch			1.16	1.50	1.58	2.99
3rd branch			1.11	1.32	1.46	2.19
4th branch			1.11	1.32	1.46	2.19
5th branch			0.98	1.33	1.58	2.06
6th branch			0.16	1.23	1.58	1.88
7th branch				1.38	1.38	2.23
8th branch				1.27		1.88
9th branch				1.56		
Immature pod				0.94	1.38	
Shell of immature pod					1.00	3.23
Seed of immature pod					0.63	0.54
Shell of mature pod						1.17
Seed of mature pod						0.32

APPENDIX XVII THE MAGNESIUM CONTENT OF THE VARIOUS PARTS
OF THE RED KIDNEY BEAN PLANTS AT SIX STAGES
OF GROWTH (PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	0.34	0.34	0.39	0.47	0.43	0.44
Cotyledon	0.27	--	--	--	--	--
Petiole of primary leaf	0.34	0.29	0.23			
Leaf blade of primary "	0.47	1.24	1.46			
Petiole of 1st true leaf		0.19				
Leaf blade of 1st true "		0.87				
Petiole of 2nd true leaf		0.04				
Leaf blade of 2nd true "		0.74				
Petiole of third true leaf		0.04				
Leaf blade of 3rd true "		0.59				
Miscellaneous		0.46	0.31	0.49		
Petiole of older leaf				0.78	0.78	0.64
Leaf blade of older "				1.47	1.26	1.17
Petiole of large leaf			0.38	0.58	0.58	
Leaf blade of large leaf			1.04	1.17	1.16	
Petiole of small leaf				0.45	0.50	
Leaf blade of small leaf				0.78	1.00	
Immature pod				0.50	0.49	
Shell of immature pod					0.44	0.49
Seed of immature pod					0.25	0.21
Shell of mature pod						0.51
Seed of mature pod						0.36

APPENDIX XVIII THE MAGNESIUM CONTENT OF THE VARIOUS PARTS
OF THE WHITE PEA BEAN PLANTS AT SIX STAGES
OF GROWTH (PERCENT)

Plant Part	Days after Planting					
	14	28	42	56	72	84
Stem	0.52	0.45	0.46	0.60	0.63	0.69
Cotyledon	0.47	--	--	--	--	--
Petiole of primary leaf	0.49	0.61	1.31			
Leaf blade of primary "	0.56	1.09				
Petiole of 1st true leaf		0.35				
Leaf blade of 1st " "		1.09				
Petiole of 2nd true leaf		0.24	0.43	0.76	0.64	
Leaf blade of 2nd " "		0.89	0.44	1.18	1.01	
Petiole of 3rd true leaf		0.16				
Leaf blade of 3rd " "		0.66				
Miscellaneous		0.47	0.39	0.46		
Petiole of older leaf			0.64	1.18	0.99	0.49
Leaf blade of older "			1.35	1.49	1.24	0.95
Petiole of small leaf			0.35	0.44	0.46	
Leaf blade of small leaf			0.62	0.82	0.71	
1st branch			0.48	0.49	0.50	0.46
2nd branch			0.47	0.54	0.56	0.76
3rd branch			0.45	0.46	0.48	0.64
4th branch			0.47	0.58	0.54	0.64
5th branch			0.40	0.57	0.48	0.64
6th branch			0.10	0.42	0.50	0.55
7th branch				0.49	0.44	0.55
8th branch				0.39	--	0.53
9th branch				0.46	--	
Immature pod				0.41	0.43	
Shell of immature pod					0.40	0.96
Seed of immature pod					0.30	0.22
Shell of mature pod						0.49
Seed of mature pod						0.21

APPENDIX XIX THE COPPER CONTENT OF THE VARIOUS PARTS OF
THE RED KIDNEY BEAN PLANTS AT SIX STAGES
OF GROWTH (ppm)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	15.0	13.3	8.3	10.0	12.1	5.8
Cotyledon	5.8	--	--	--	--	--
Petiole of primary leaf	10.8	16.7	9.7			
Leaf blade of primary "	10.8	14.2	14.2			
Petiole of 1st true leaf		24.1				
Leaf blade of 1st true "		15.0				
Petiole of 2nd true leaf		5.0				
Leaf blade of 2nd true "		13.3				
Petiole of 3rd true leaf		5.0				
Leaf blade of 3rd true "		13.3				
Miscellaneous		13.3	17.9	25.0		
Petiole of older leaf				20.0	14.2	23.3
Leaf blade of older "				17.9	21.7	17.5
Petiole of large leaf			12.1	20.0	19.1	
Leaf blade of large leaf			17.0	20.0	18.7	
Petiole of small leaf				14.2	18.7	
Leaf blade of small leaf				32.5	18.7	
Immature pod				17.1	10.8	
Shell of immature pod					10.8	6.7
Seed of immature pod					13.3	6.7
Shell of mature pod						5.0
Seed of mature pod						6.7

APPENDIX XX THE COPPER CONTENT OF THE VARIOUS PARTS OF
THE WHITE PEA BEAN PLANTS AT SIX STAGES OF
GROWTH (ppm)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	10.8	9.1	9.7	12.5	13.3	10.0
Cotyledon	7.9	--	--	--	--	--
Petiole of primary leaf	11.2	12.1	} 12.5			
Leaf blade of primary "	8.3	10.8				
Petiole of 1st true leaf		10.8				
Leaf blade of 1st " "		12.1				
Petiole of 2nd true leaf		9.7	9.7	17.9	12.1	
Leaf blade of 2nd " "		12.5	14.2	21.7	8.3	
Petiole of 3rd true leaf		12.0				
Leaf blade of 3rd true "		15.8				
Miscellaneous		13.3	18.7	26.8		
Petiole of older leaf			18.7	16.7	8.3	7.9
Leaf blade of older leaf			15.0	15.0	8.3	17.5
Petiole of small leaf			9.2	17.9	17.1	
Leaf blade of small leaf			15.0	25.0	8.3	
1st branch			9.7	18.7	8.3	8.3
2nd branch			13.3	14.2	10.0	8.3
3rd branch			12.1	14.2	5.8	5.8
4th branch			20.0	16.7	5.8	5.8
5th branch			25.8	17.5	5.8	5.8
6th branch			5.0	15.8	10.0	6.7
7th branch				15.8	10.0	17.5
8th branch				17.1	--	} 19.1
9th branch				18.7	--	
Immature pod				18.7	14.2	
Shell of immature pod					14.2	16.7
Seed of immature pod					10.0	9.6
Shell of mature pod						3.3
Seed of mature pod						10.0

APPENDIX XXI THE IRON CONTENT OF THE VARIOUS PARTS OF
THE RED KIDNEY BEAN PLANTS AT SIX STAGES
OF GROWTH (ppm)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	83.2	83.2	191.5	250	183.2	50.0
Cotyledon	183.2	--	--	--	--	--
Petiole of primary leaf	183.2	324.9	191.5			
Leaf blade of primary "	324.9	83.0	1000.0			
Petiole of 1st true leaf		150.0				
Leaf blade of 1st true "		412.4				
Petiole of 2nd true leaf		50.0				
Leaf blade of 2nd true "		433.2				
Petiole of 3rd true leaf		50.0				
Leaf blade of 3rd true "		208.3				
Miscellaneous		200.0	100.0	500.0		
Petiole of older leaf				350.0	200.0	491.7
Leaf blade of older "				917.0	360.0	41.5
Petiole of large leaf			324.9	350.0	208.3	
Leaf blade of large "			450.0	500.0	360.0	
Petiole of small leaf				283.2	341.5	
Leaf blade of small "				500.0	624.0	
Immature pod				241.5	200.0	
Shell of immature pod					50.0	83.2
Seed of immature pod					150.0	54.1
Shell of mature pod						483.2
Seed of mature pod						54.1

APPENDIX XXII THE IRON CONTENT OF THE VARIOUS PARTS OF
THE WHITE PEA BEAN PLANTS AT SIX STAGES
OF GROWTH (ppm)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	191.5	91.5	58.3	58.3	133.2	166.6
Cotyledon	249.0	--	--	--	--	--
Petiole of primary leaf	249.0	360.0	624			
Leaf blade of primary "	324.0	360.0				
Petiole of 1st true leaf		100				
Leaf blade of 1st " "		412.4				
Petiole of 2nd true leaf		83.0	150.0	150.0	208.0	
Leaf blade of 2nd " "		300.0	250.0	466.6	360.0	
Petiole of 3rd true leaf		83.0				
Leaf blade of 3rd " "		183.2				
Miscellaneous		250.0	208.0	333.2		
Petiole of older leaf			208.3	450.0	324.9	54.1
Leaf blade of " "			624.0	832.0	290.0	1917.0
Petiole of small leaf			83.2	191.5	208.3	
Leaf blade of " "			250.0	832.0	483.2	
1st branch			100.0	58.3	50.0	250.0
2nd branch			133.2	83.2	83.2	433.2
3rd branch			133.2	83.2	100.0	333.2
4th branch			150.0	83.2	100.0	324.9
5th branch			240.0	83.2	58.3	300.0
6th branch			58.3	83.2	58.3	290.0
7th branch				83.2	66.6	300.0
8th branch				290.0	--	316.6
9th branch				290.0	--	
Immature pod				150.0	83.2	
Shell of immature pod					133.2	466.0
Seed of immature pod					58.3	50.0
Shell of mature pod						100.0
Seed of mature pod						54.1

APPENDIX XXIII THE MANGANESE CONTENT OF THE VARIOUS PARTS
OF THE RED KIDNEY BEAN PLANTS AT SIX
STAGES OF GROWTH (ppm)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	12.4	19.3	19.4	12.4	8.3	29.0
Cotyledon	29.0	--	--	--	--	--
Petiole of primary leaf	18.5	19.4	9.7			
Leaf blade of primary "	27.0	68.7	74.9			
Petiole of the 1st true leaf		19.4				
Leaf blade of the 1st true leaf		68.7				
Petiole of the 2nd true leaf		5.1				
Leaf blade of the 2nd true leaf		50.0				
Petiole of the 3rd true leaf		2.8				
Leaf blade of the 3rd true leaf		34.9				
Miscellaneous		35.3	8.3	22.2		
Petiole of older leaf				21.5	44.0	33.2
Leaf blade of older leaf				74.9	66.6	91.5
Petiole of large leaf			22.2	27.7	44.0	
Leaf blade of large leaf			62.4	29.0	66.6	
Petiole of small leaf				72.2	22.2	
Leaf blade of small leaf				29.0	66.6	
Immature pod				11.1	27.7	
Shell of immature pod					22.2	12.4
Seed of immature pod					8.3	12.4
Shell of mature pod						29.0
Seed of mature pod						5.6

APPENDIX XXIV THE MANGANESE CONTENT OF THE VARIOUS PARTS
OF THE WHITE PEA BEAN PLANTS AT SIX STAGES
OF GROWTH (ppm)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	11.1	33.2	11.1	12.4	21.5	5.6
Cotyledon	18.7	--	--	--	--	-
Petiole of primary leaf	21.0	27.0	} 88.8			
Leaf blade of " "	22.2	108.0				
Petiole of 1st true "		24.9				
Leaf blade of 1st " "		97.2				
Petiole of 2nd true leaf		22.2	20.7	13.9	18.7	
Leaf blade of 2nd " "		77.0	35.3	52.1	61.1	
Petiole of 3rd true leaf		20.7				
Leaf blade of 3rd true "		66.6				
Miscellaneous		52.1	27.7	35.3		
Petiole of older leaf			18.7	33.2	20.7	18.7
Leaf blader of " "			68.1	61.1	63.9	88.8
Petiole of small leaf			12.4	13.9	22.2	
Leaf Blade of small leaf			33.2	43.6	58.3	
1st branch			11.1	8.3	8.3	21.5
2nd branch			19.4	18.7	12.4	13.9
3rd branch			20.7	18.7	20.7	13.9
4th branch			12.4	19.4	11.1	13.9
5th branch			16.6	19.4	16.6	13.9
6th branch			6.0	8.3	19.4	16.6
7th branch				8.3	12.4	20.7
8th branch				46.0	-	21.5
9th branch				46.0	-	
Immature Pod				27.0	12.4	
Shell of immature pod					21.5	24.9
Seed of immature pod					19.4	22.2
Shell of mature pod						16.6
Seed of mature pod						20.7

APPENDIX XXV THE ZINC CONTENT OF THE VARIOUS PARTS OF THE
KIDNEY BEAN PLANTS AT SIX STAGES OF GROWTH
(ppm)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	27.6	12.7	21.7	16.3	12.9	16.8
Cotyledon	24.4	--	--	--	--	--
Petiole of primary leaf	19.1	20.7	17.4			
Leaf Blade of " "	25.1	16.3	25.9			
Petiole of 1st true leaf		8.05				
Leaf blade of 1st " "		10.0				
Petiole of 2nd true leaf		29.1				
Leaf blade of 2nd " "		27.6				
Petiole of 3rd true leaf		16.8				
Leaf blade of 3rd " "		21.7				
Miscellaneous		35.9	20.6	56.8		
Petiole of older leaf				25.1	24.60	24.1
Leaf blade of " "				28.0	30.0	35.1
Petiole of large leaf			21.7	24.1	14.6	
Leaf blade of large leaf			27.4	28.0	32.3	
Petiole of small leaf				26.3	29.5	
Leaf blade of small leaf				50.8	35.9	
Immature pod				39.7	27.6	
Shell of immature pod					24.6	12.6
Seed of immature pod					41.2	23.4
Shell of mature pod						25.4
Seed of mature pod						30.8

APPENDIX XXVI THE ZINC CONTENT OF THE VARIOUS PARTS OF THE
WHITE PEA BEAN PLANTS AT SIX STAGES OF GROWTH
(ppm)

Plant Part	Days after Planting					
	14	28	42	56	70	84
Stem	15.9	15.7	20.3	17.4	18.5	18.5
Cotyledon	20.4	--	--	--	--	--
Petiole of primary leaf	59.7	26.4	} 18.5			
Leaf blade of primary "	16.6	21.7				
Petiole of 1st true leaf		8.5				
Leaf blade of 1st " "		6.3				
Petiole of 2nd true leaf		42.5	18.5	16.3	14.0	
Leaf blade of 2nd " "		12.9	20.8	24.6	17.6	
Petiole of 3rd true leaf		42.5				
Leaf blade of 3rd " "		12.9				
Miscellaneous		20.3	44.6	46.8		
Petiole of older leaf			18.5	20.6	22.3	20.8
Leaf blade of older leaf			24.0	19.7	19.4	30.0
Petiole of small leaf			20.7	17.6	15.1	
Leaf blade of small leaf			24.4	24.0	22.5	
1st branch			20.3	22.3	18.9	20.6
2nd branch			23.4	30.0	16.8	15.7
3rd branch			25.1	27.4	14.6	17.4
4th branch			21.2	28.5	15.9	13.4
5th branch			35.9	30.6	14.6	16.3
6th branch			14.6	25.9	16.8	17.4
7th branch				26.8	14.6	12.5
8th branch				42.5		} 38.5
9th branch				42.5		
Immature pod				32.3	18.0	
Shell of immature pod					14.6	28.0
Seed of immature pod					24.6	24.2
Shell of mature pod						10.0
Seed of mature pod						21.7

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